DØ: Recent updates and 2010 physics prospects

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for the DØ Collaboration

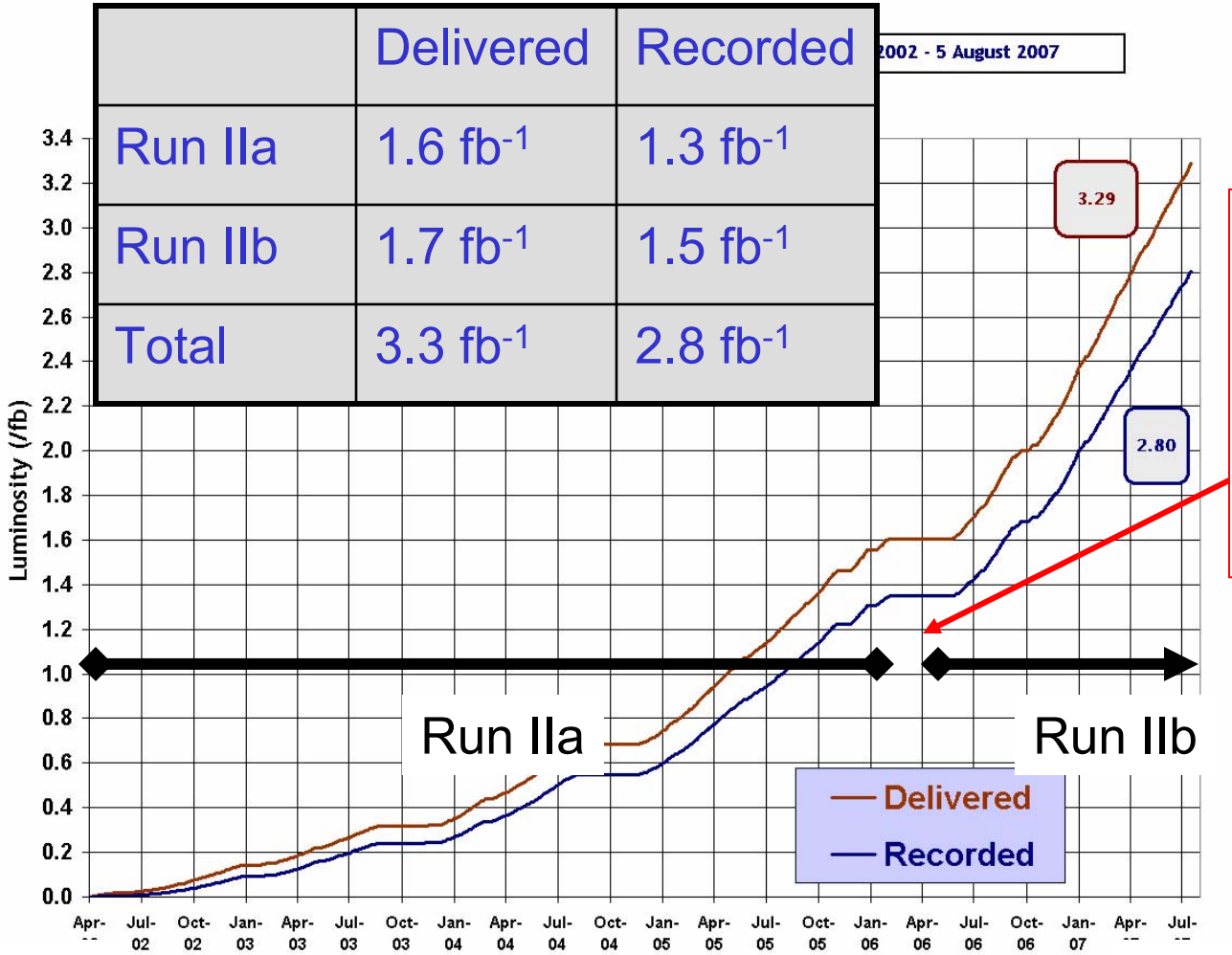
Particle Physics Project Prioritization Panel (P5) Meeting, September, 2007, Fermilab

Outline

- Where we are:
  - Luminosity delivered, recorded, and analyzed
  - Update on recent physics results
- Where we are going:
  - Luminosity expectations and assumptions
  - Projection to 2010 for selected physics topics:
    - **Standard Model Higgs**
    - **SUSY Higgs**
    - **$B_s \rightarrow \mu\mu$**
  - Broader view of impact of 2010 running on physics prospects
- Tevatron and LHC
- Conclusions

Integrated Luminosity

	Delivered	Recorded
Run IIa	1.6 fb^{-1}	1.3 fb^{-1}
Run IIb	1.7 fb^{-1}	1.5 fb^{-1}
Total	3.3 fb^{-1}	2.8 fb^{-1}



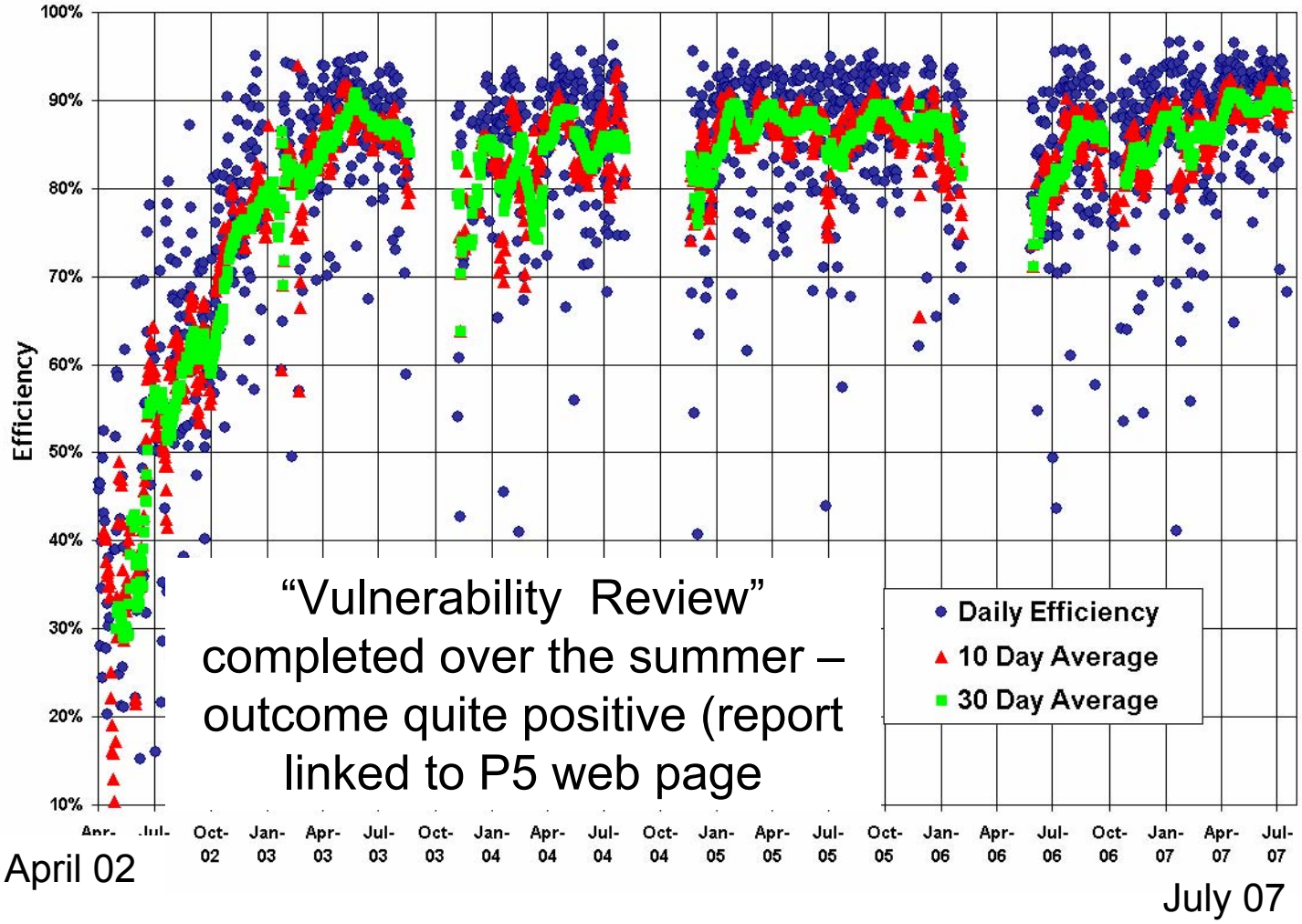
2006 shutdown:

- new Layer 0 silicon installed
- trigger upgrades installed

April 02 July 07

Data Taking Efficiency

Definition: recorded luminosity / delivered luminosity



"Vulnerability Review" completed over the summer – outcome quite positive (report linked to P5 web page

April 02

July 07

average efficiency = 87%

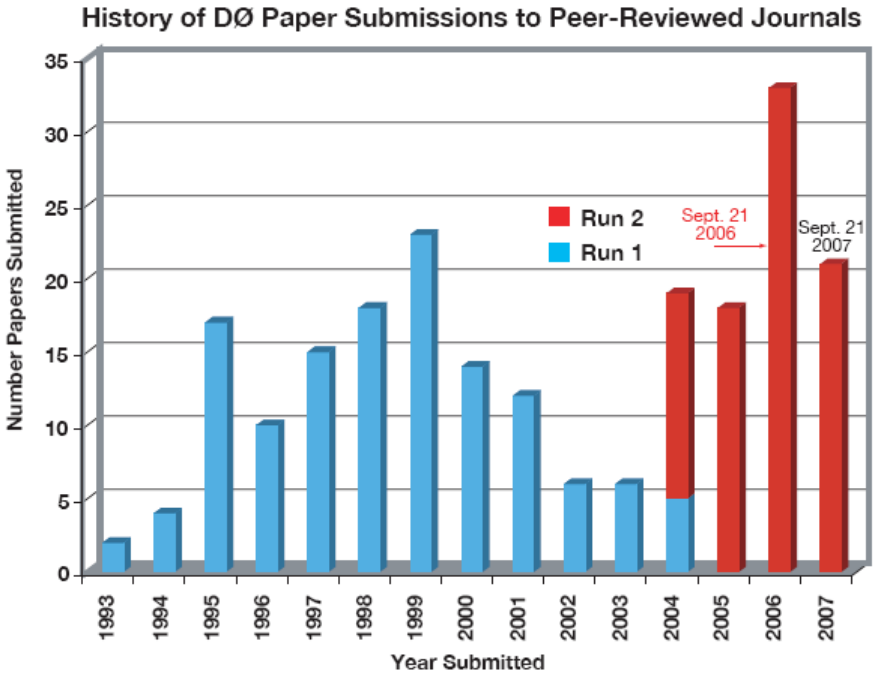
Sources of loss:

- Readout dead time
- Starting/stopping runs
- Begin/end of store
- Down time for detector problems

Small dead time even at high luminosity

Tally of New Results

- Since the last P5 meeting in June:
  - **More than 30 new results** presented at Summer conferences (EPS and Lepton-Photon)
  - New from all physics areas physics, Electroweak, New Phenomena Searches, QC Top Quark Physics, Higgs Searches
  - Some have improved techniques, some with increased luminosity (and some a combination of these)
  - Some completely new topics now explored due to larger samples and/or new theoretical developments



- Publications
  - 21 so far in 2007
  - On track to equal 2006 peak in 2007

New EW & QCD Results

- $\sigma(W+c\text{-jets})/\sigma(W+jets)$
- $d\sigma/dp_T(Z)$
- $\sigma(WZ)$ and anomalous couplings
- $Z\gamma$ Production and anomalous couplings‡
- $\sigma(pp\text{->}Z)*B(Z\text{->}\tau\tau)$
- Measurement of $\Upsilon(1S)$ & $\Upsilon(2S)$ polarization

‡publication

Example Result: Z->ττ

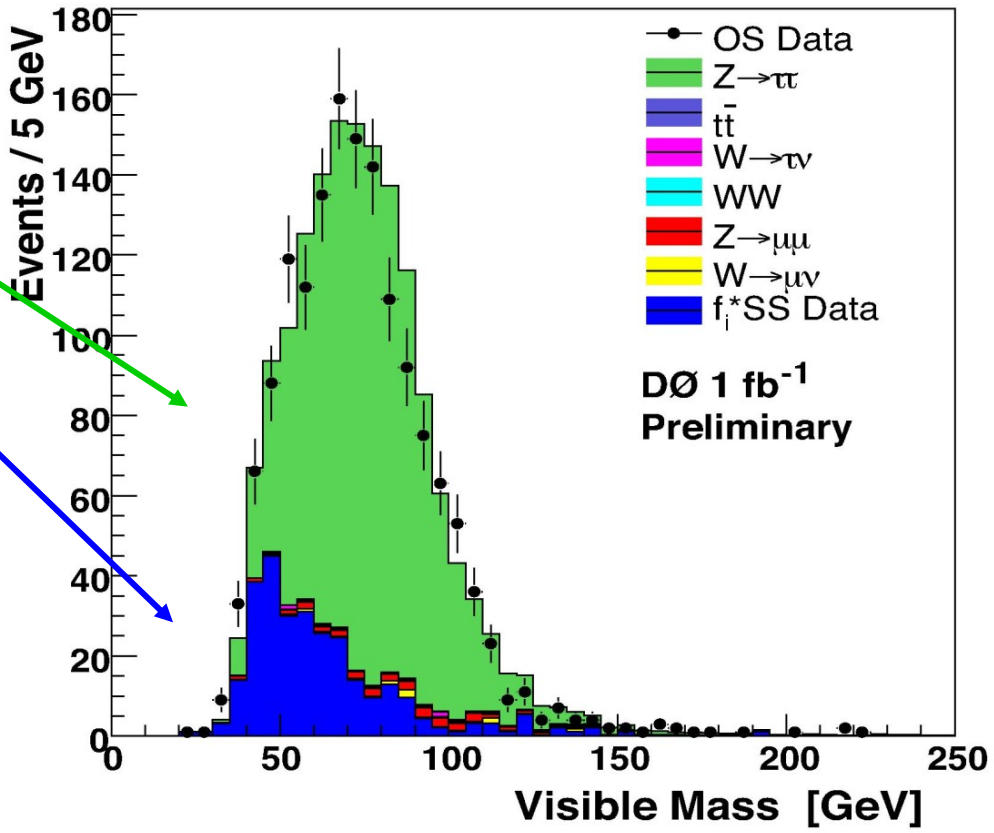
Method

Use Z -> ττ -> $\mu+\tau_h$

Signal prediction

Instrumental Bkg (from opposite sign vs. same sign)

- Illustrates success in tau identification.
- Increases confidence in our τ_h results.



$\sigma(pp\text{->}Z)*B(Z\text{->}\tau\tau) = 247 \pm 8(stat) \pm 13(sys) \pm 15(lumi)$ pb

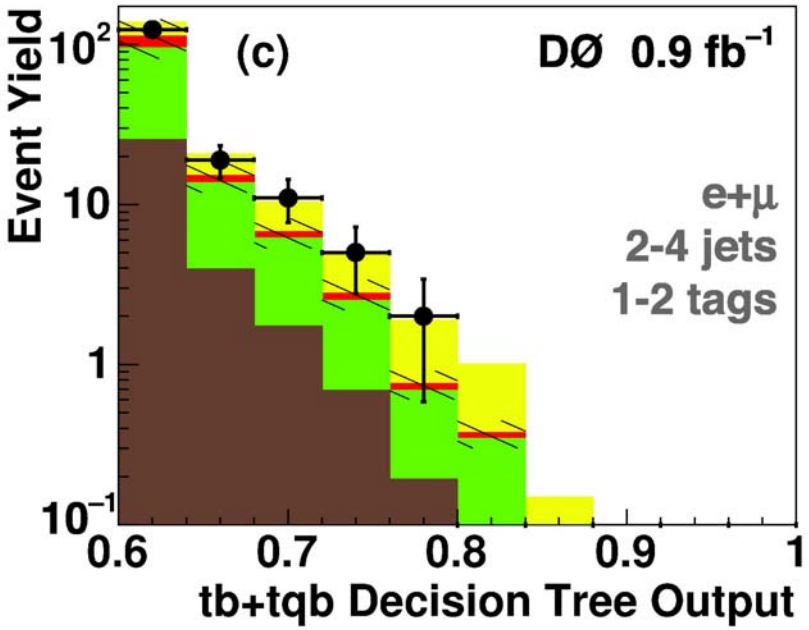
compare to prediction $252\ ^{+5.0}_{-12}$ pb Hamberg, van Neerven & Matsuura, Nucl. Phys. B 359, 343.

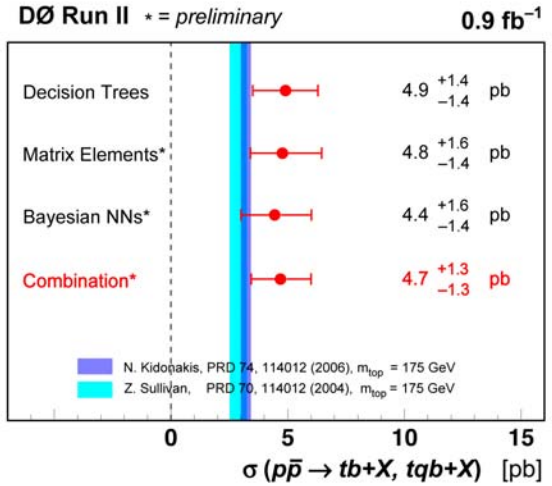
Top Physics: New Results

- Top Mass
  - m_t, dilepton matrix element weighting
    - and combination
  - m_t from $\sigma(tt)$
- Cross sections
  - $\sigma(tt)$ in lepton + track
  - $\sigma(tt)$ in lepton $+\tau_h$
  - $\sigma(tt)$ in dileptons‡
  - $\sigma(tt)$, dilepton combination
  - $\sigma(tt)$ in lepton + jets‡
  - B(t->Wb)/B(t->Wq) & σ
- New Physics in Prod/Decay
  - Search for stop in ttbar
  - ttbar Charge Asymmetry
  - W helicity in top decay
  - ttbar resonance search
  - σ(tt; lepton+jets)/σ(tt; dileptons)
- Single top
  - update on single top cross section
  - search for flavor changing neutral currents in single top production‡

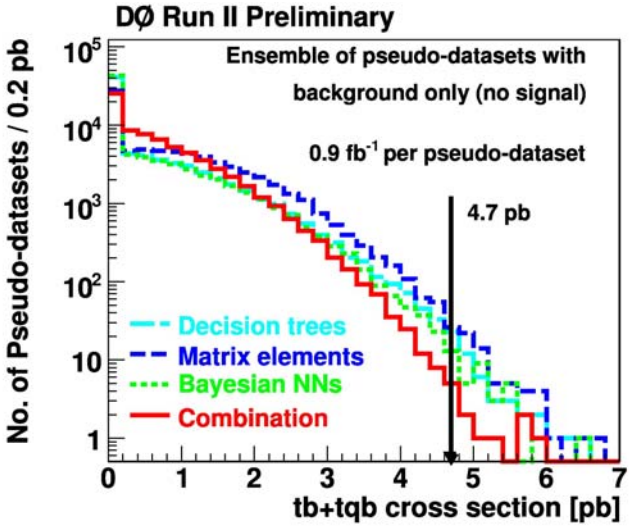
‡publication

Example result: single top



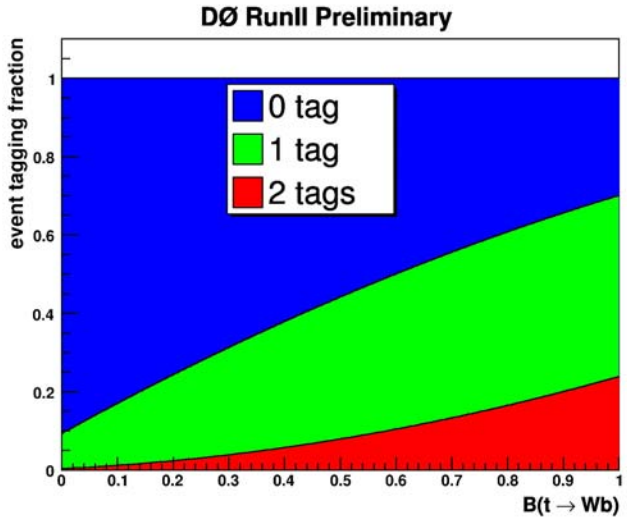


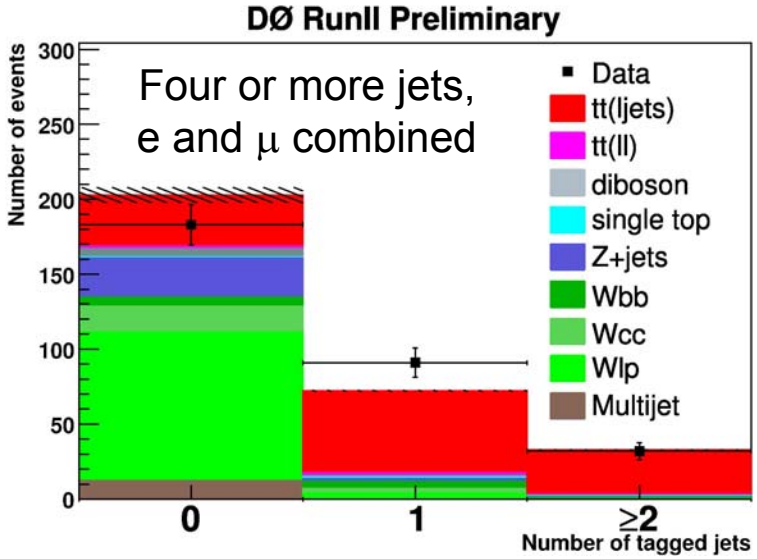
0.68<|*Vtb*| ≤1 at 95% C.L.

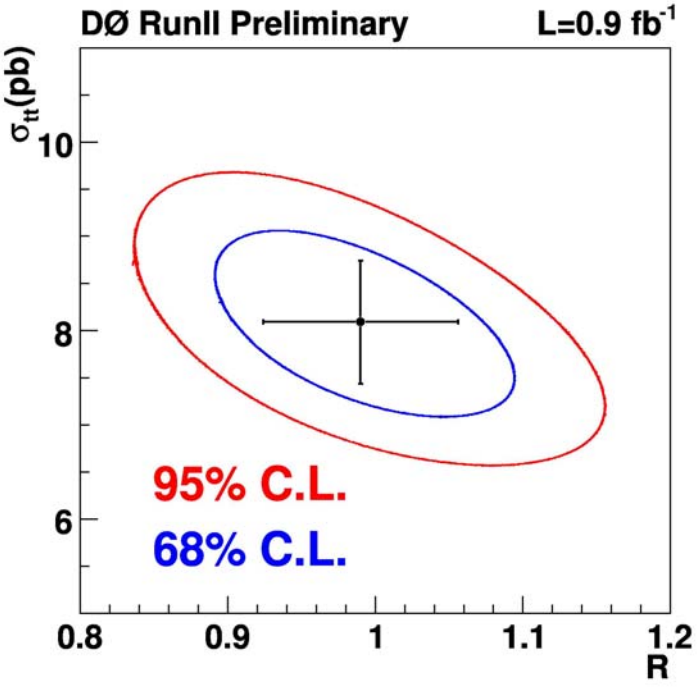


- First evidence of single top production published in May (PRL 98 181802) – was 3.4 σ
- Result updated this summer with improvements to some of the mutivariate discriminants
- significance increase to 3.6 σ

Example result: simultaneous measurement of σ(ppbar→ttbar+X) and R=B(t→Wb)/B(t→Wq)







$$R = 0.991^{+0.094}_{-0.085}(\text{stat} + \text{syst})$$

$$\sigma(t\bar{t}) = 8.10^{+0.87}_{-0.82}(\text{stat} + \text{syst}) \pm 0.49(\text{lum})\text{pb}$$

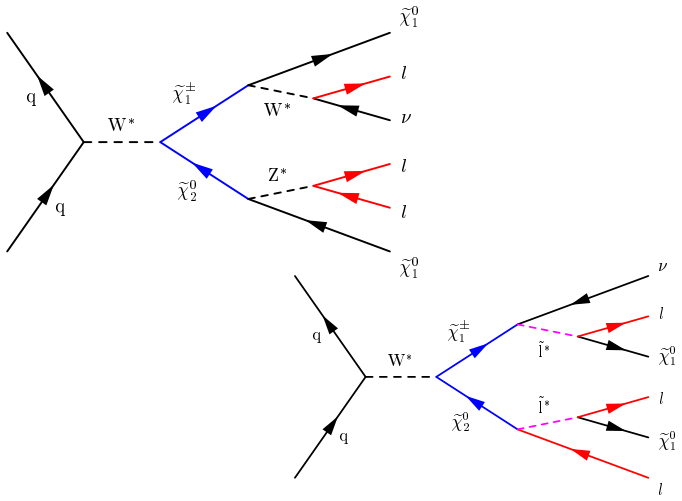
World's best measurement of R

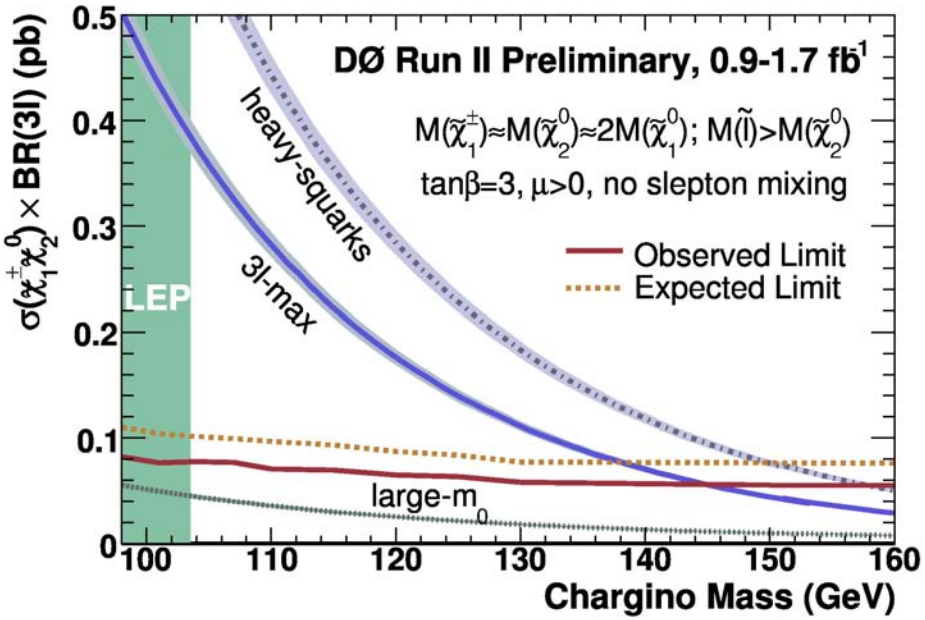
Beyond the SM Searches: New Results

- SUSY searches
  - stop $\rightarrow$ c + χ^0
  - stop pairs in dileptons + missing E_T + b-jets‡
  - squark search in τ_h + jets + missing E_T
  - $\chi^{\pm}\chi^0$ in trileptons, eeℓ
  - Gauge Mediated SUSY Breaking in $\gamma\gamma$
- Non-SUSY
  - 3rd generation leptoquarks in $\tau\tau$bb
  - 3rd generation leptoquarks in b-tagged jets + missing E_T‡
  - b' -> Z+b, "Long Lived Parents of Z's"
- Beyond the standard SM Higgs
  - H -> $\gamma\gamma$
  - H++H$^{--}\rightarrow \mu^+\mu^+\mu^-\mu^-$

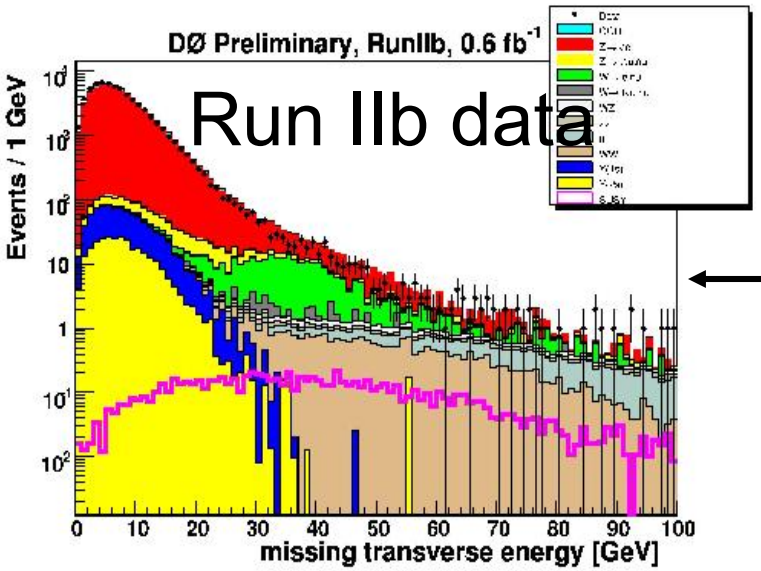
‡publication

Example BSM Search: SUSY Chargino/Neutralino →trileptons





- New result in eeℓ



After initial selection

After partial selection

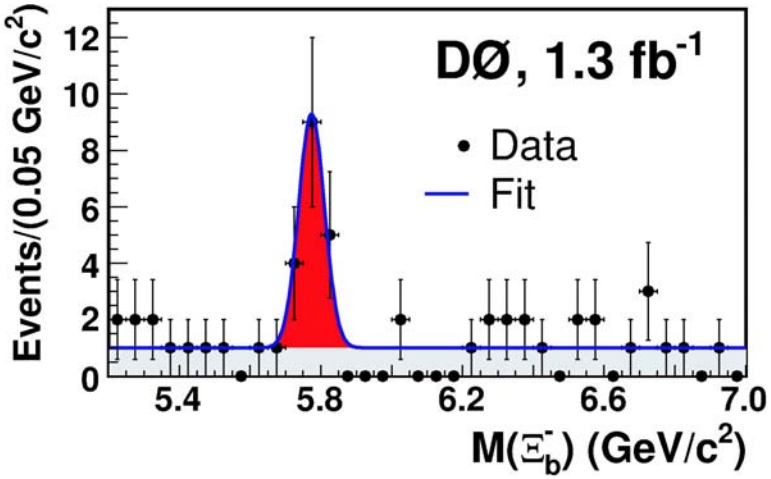
Predicted Background	208 ± 7
Data	182

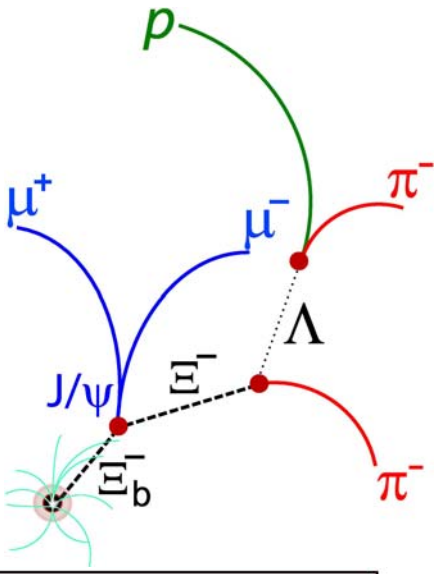
B Physics: New results

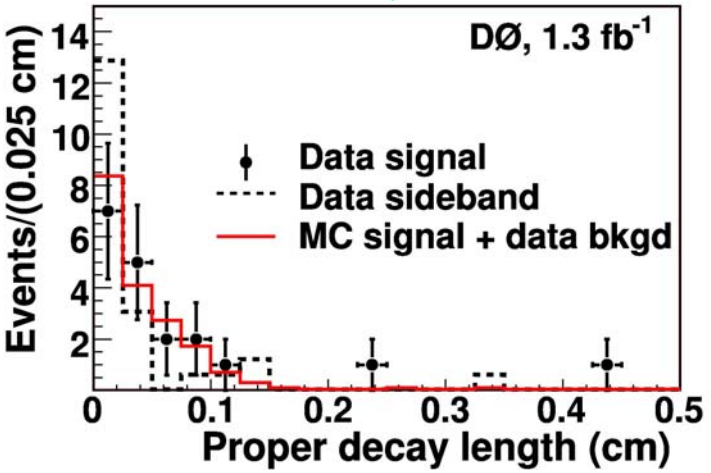
- Discovery of Ξ_b ‡
- B_s Mixing Frequency Measurement
- Search for B_s–> μ+μ- Decay (1 fb^{-1}‡; 2 fb^{-1})
- Λ_b lifetime in semileptonic decay‡
- Direct CP violation in B^+ -> J/ψ K^+
- Search for Flavor Changing Neutral Currents in D Meson Decays‡
- Observation of B**‡

‡publication

Example result: Ξ_b^- Discovery





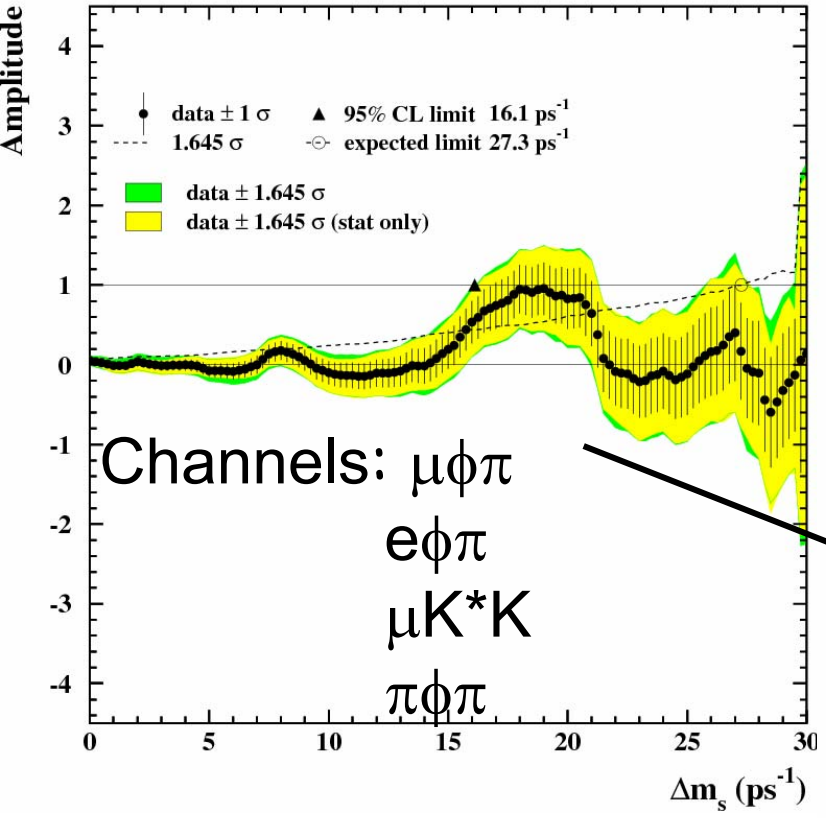


$M(\Xi_b^-) = 5.774 \pm 0.019$ GeV/c^2

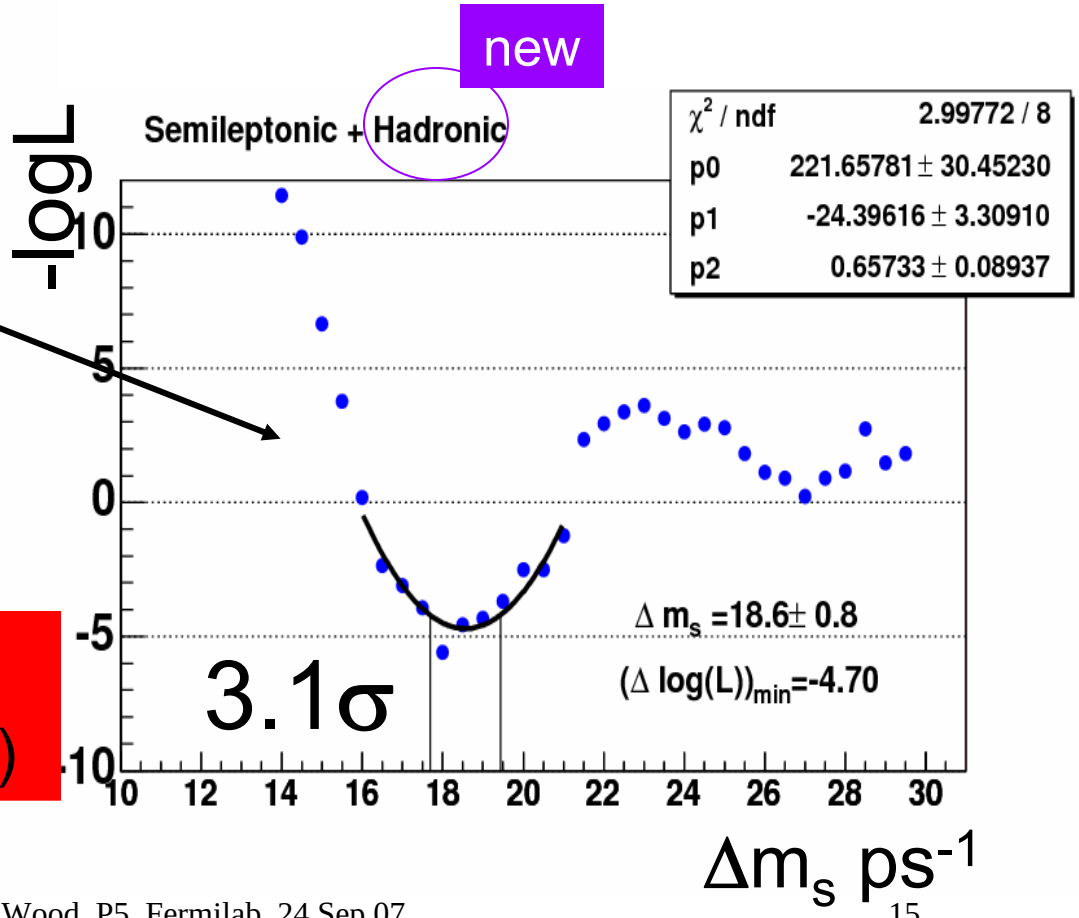
PRL 99, 1052001 (2007)

$$\frac{f(b \to \Xi_b^-) \cdot Br(\Xi_b^- \to J/\psi\, \Xi^-)}{f(b \to \Lambda_b) \cdot Br(\Lambda_b \to J/\psi\, \Lambda)} = 0.28 \pm 0.09\,(\text{stat.})^{+0.09}_{-0.08}\,(\text{syst.}).$$

Example result: B_s Mixing



$$\Delta m_s = 18.6 \pm 0.8 \text{ps}^{-1}$$

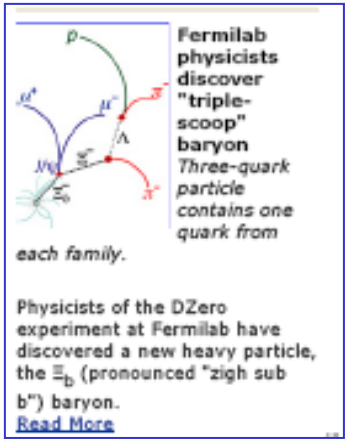


2.4 fb^{-1}
(Data thru end May 2007)

Summer 2007: Special milestones

- **June:** Two major awards for DØ physicist at annual Fermilab Users Meeting
  - URA Thesis Award to **Tim Scanlon**, Imperial College
    - "b-Tagging and the Search for Neutral Supersymmetric Higgs Bosons at D0 "
  - AlvinTollestrup Award for Outstanding Postdoctoral Research to **Yann Coadou**, Simon Fraser University
    - for his work on extracting the first evidence for single top production
- **June:** Discovery of the Ξ_b^-
  - "triple scoop baryon"
- **August:** 200th DØ publication appears in print ("Direct Observation of the Strange b Baryon Ξ_b^- ")
  - Special collaboration celebration this Wednesday
- **September**: DØ physicist **Jan Stark** receives "Médaille de Bronze" from CNRS in France

Fermilab press release from June 13th

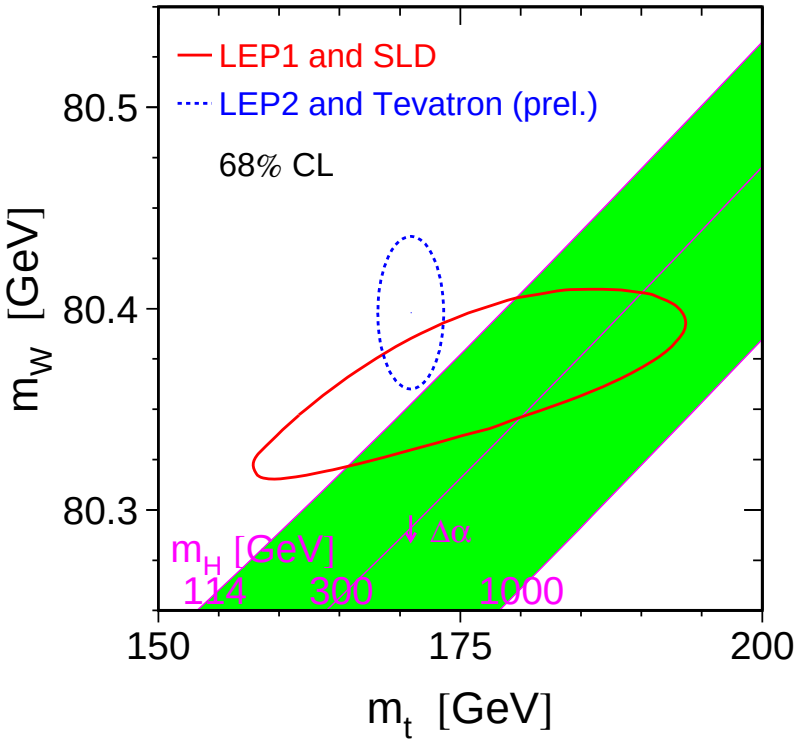


2010 Running: Parameters

- Based on estimates from Fermilab accelerator division, we anticipate
  - about 6.8 fb^{-1} delivered by end of FY09
  - about 8.5 fb^{-1} delivered by end of FY10 with a 2010 run
- We estimate about 80% of this delivered luminosity will finally be used in analyses
  - **5.5 fb^{-1}** by end of FY09
  - **6.8 fb^{-1}** by end of FY10 (=25% increase over FY09)
- **We will use "analyzed luminosity" for remaining projections so the projected results can be compared easily with existing results**

Physics projection 1: SM Higgs search

- The mechanism of electroweak symmetry breaking (EWSB) and the origin of mass is one of the outstanding questions in particle physics
- If the minimal Standard Model is correct, a scalar Higgs boson is responsible for EWSB.
- Indirect constraints (including Tevatron measurements of the top mass and W boson mass) indicate that the Higgs should be fairly light
  - it could be in reach of the Tevatron



m_H<144 GeV (w/o direct exclusion)

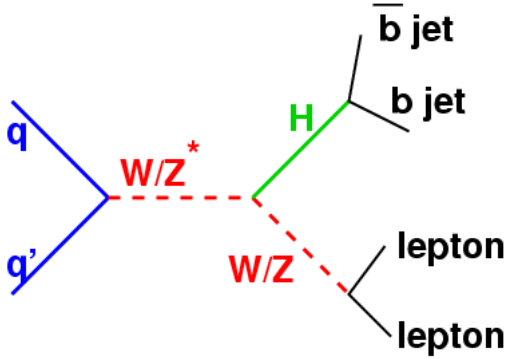
m_H<182 GeV (w/ direct exclusion)

SM Higgs search at the Tevatron

Low mass (m_H <~135 GeV):
dominant decay:

$H \to b\bar{b}$

Use associated production modes to get better signal/background



$q\bar{q}' \to WH \to \ell\nu b\bar{b}$

$q\bar{q} \to ZH \to \ell^+\ell^- b\bar{b}$

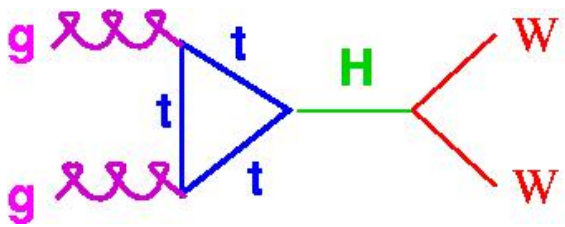
$q\bar{q} \to ZH \to \nu\bar{\nu} b\bar{b}$

Intermediate mass:

$q\bar{q} \to WH \to WWW^{(*)}$

High mass (m_H>~135 GeV):
dominant decay:

$H \to WW^{(*)}$

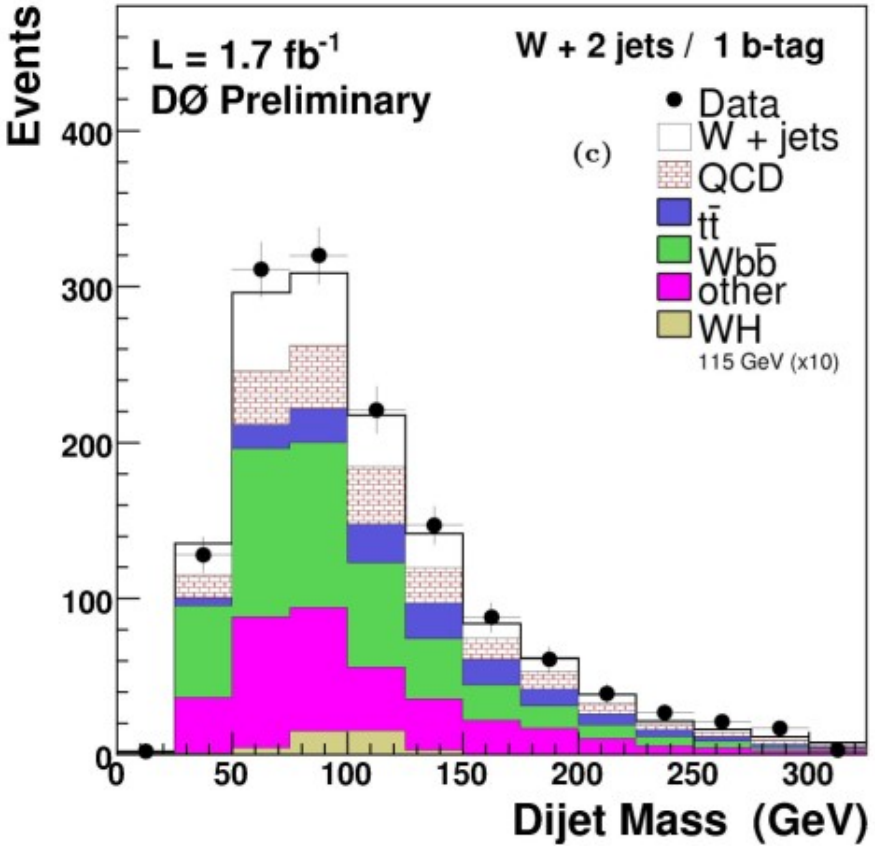


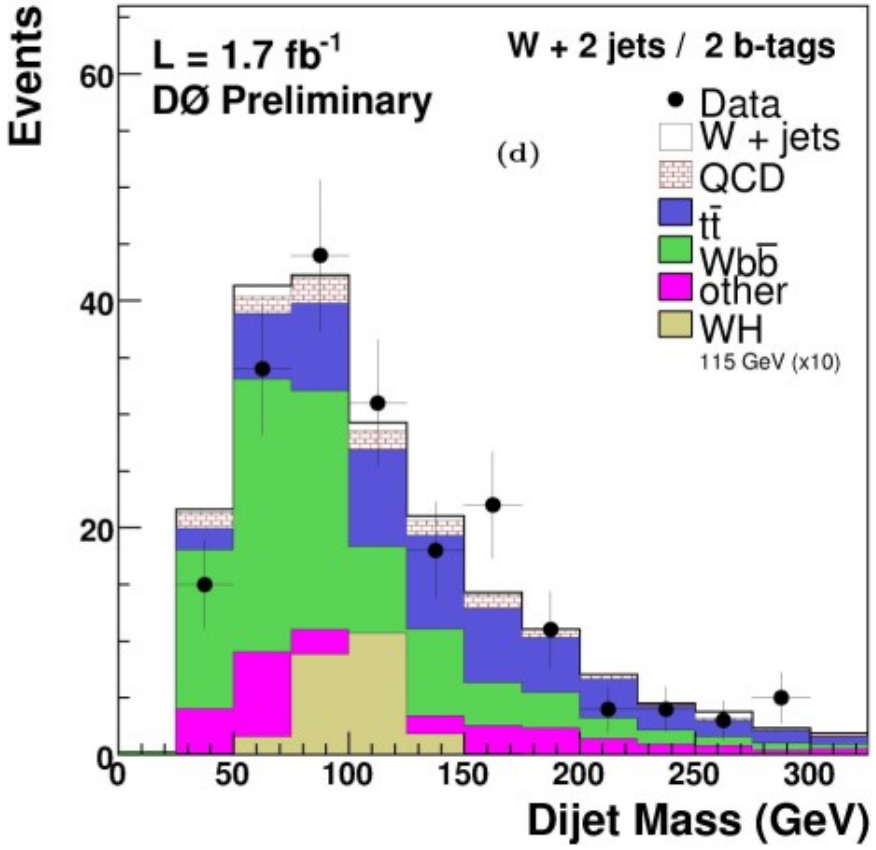
$gg \to H \to WW \to \ell\nu\ell'\nu'$

Higgs Searches: Low Mass

$WH \rightarrow \ell\nu bb$

$1.7\ fb^{-1}$





Winter '07limit (1 fb^{-1}) was based on dijet mass. Now using neural net.

Higgs Searches: Low Mass

$ZH \rightarrow \ell\,\ell\,bb$

ZH also using a Neural Network (NN) for final stage.

Fit NN output for final limit result.

Variables:

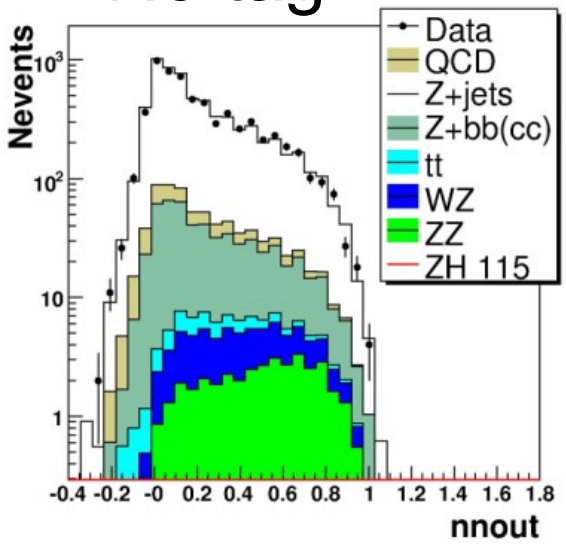
$p_{T,j1}$, $p_{T,j2}$

$\Delta R(jj)$, $p_{T,dijets}$,

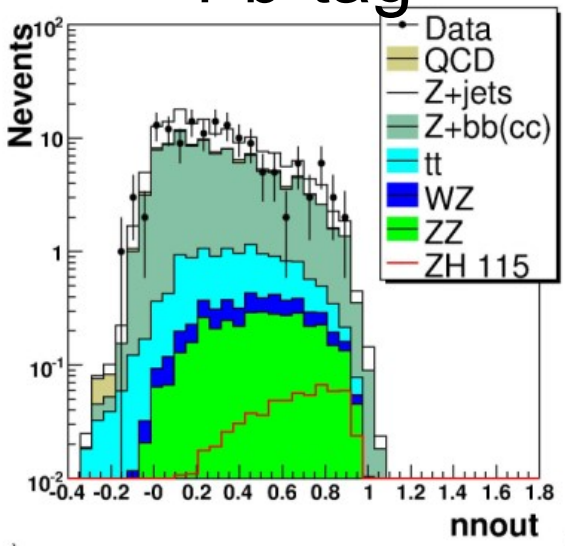
M_{JJ}, $p_{T(l,MET)}$

NN output

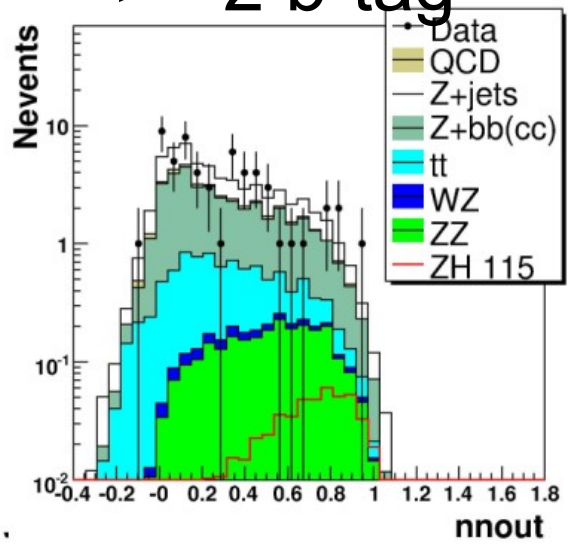
No tag



=1 b-tag



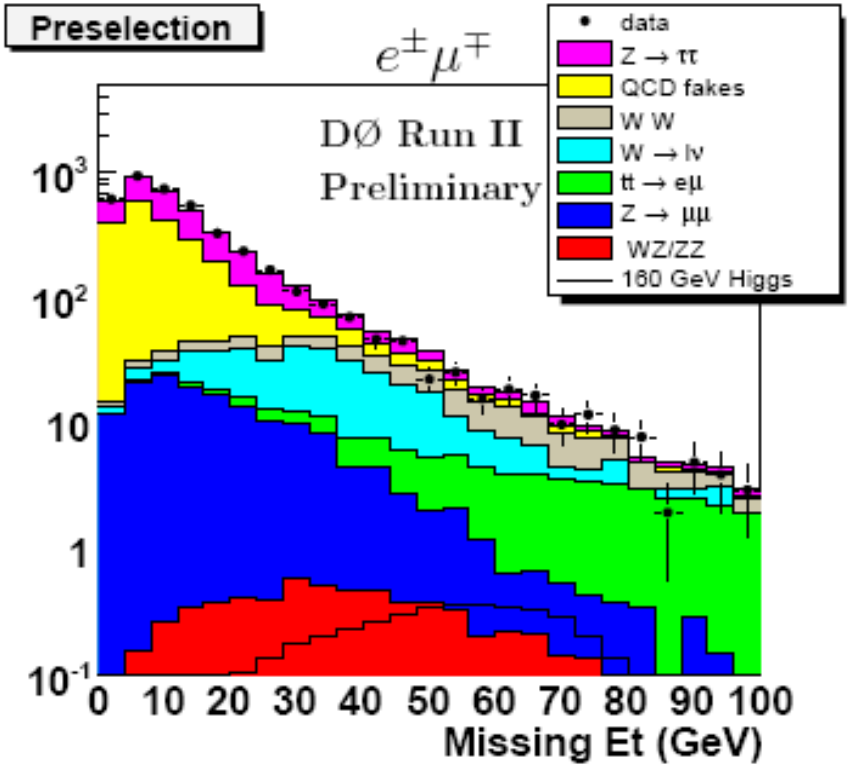
>= 2 b-tag

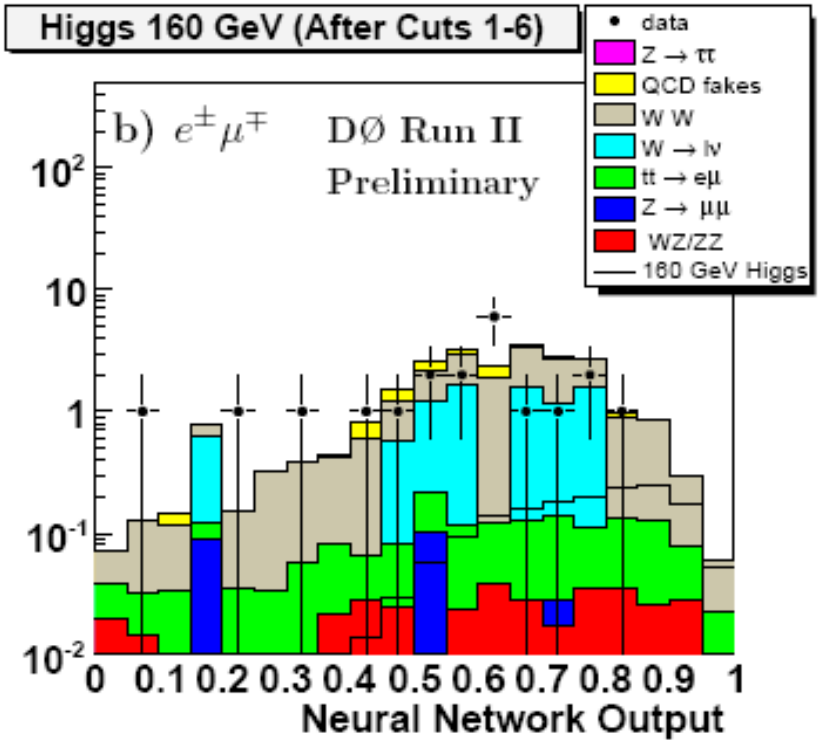


High Mass: H->WW->eμ

Basic pre-selection then multivariate for final stage

1.7 fb^{-1}





NN output

Current State of DØ SM Higgs Analyses

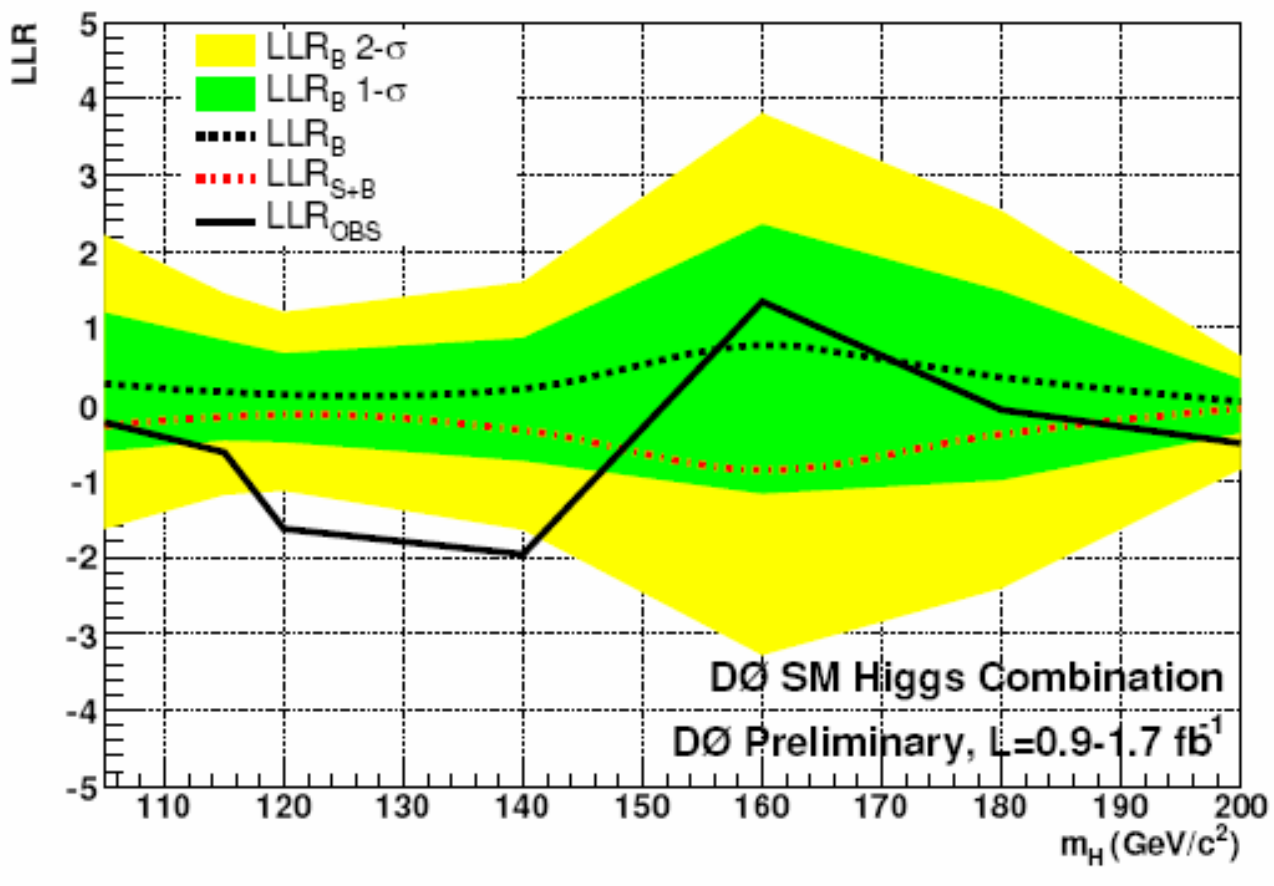
Low-mass channels

Channel	Lum used in result
$WH \to e\nu b\bar{b}$	1.7 fb-1
$WH \to \mu\nu b\bar{b}$	1.7 fb-1
$ZH \to ee b\bar{b}$	1.1 fb-1
$ZH \to \mu\mu b\bar{b}$	1.1 fb-1
$ZH \to \nu\nu b\bar{b}$	0.9 fb-1

Intermediate- and high-mass channels

Channel	Lum used in result
$WH \to WWW^* \to \ell^\pm\ell^\pm + X$	1.0 fb-1
$H \to WW \to e\nu e\nu$	1.7 fb-1
$H \to WW \to \mu\nu\mu\nu$	1.7 fb-1
$H \to WW \to e\nu\mu\nu$	1.7 fb-1
$H \to WW \to \mu\nu\tau_h\nu$	1.0 fb-1

Extraction of SM Higgs Limits



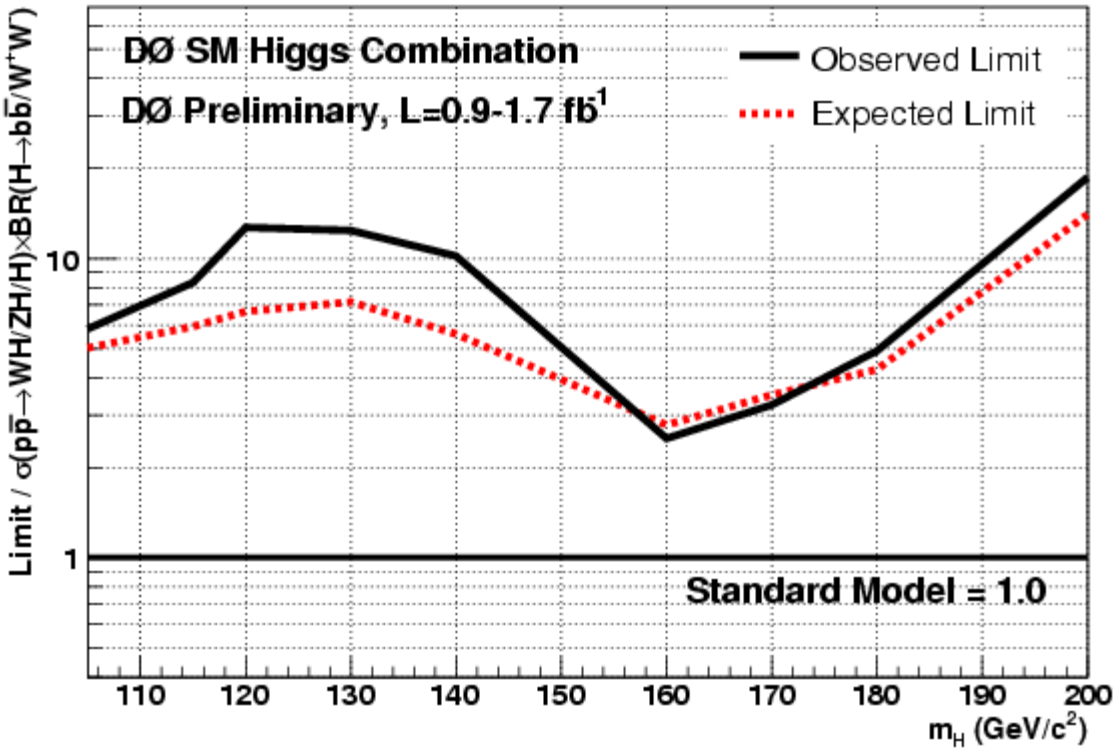
$$LLR = -2\ln(L(s+b)/L(b))$$

Current DØ SM Higgs Limits

- For m_H=115, expected (observed) 95% CL relative to σ_{SM} = 6.0 (8.3)
- For m_H=160, expected (observed) 95% CL relative to σ_{SM} = 2.8 (2.5)

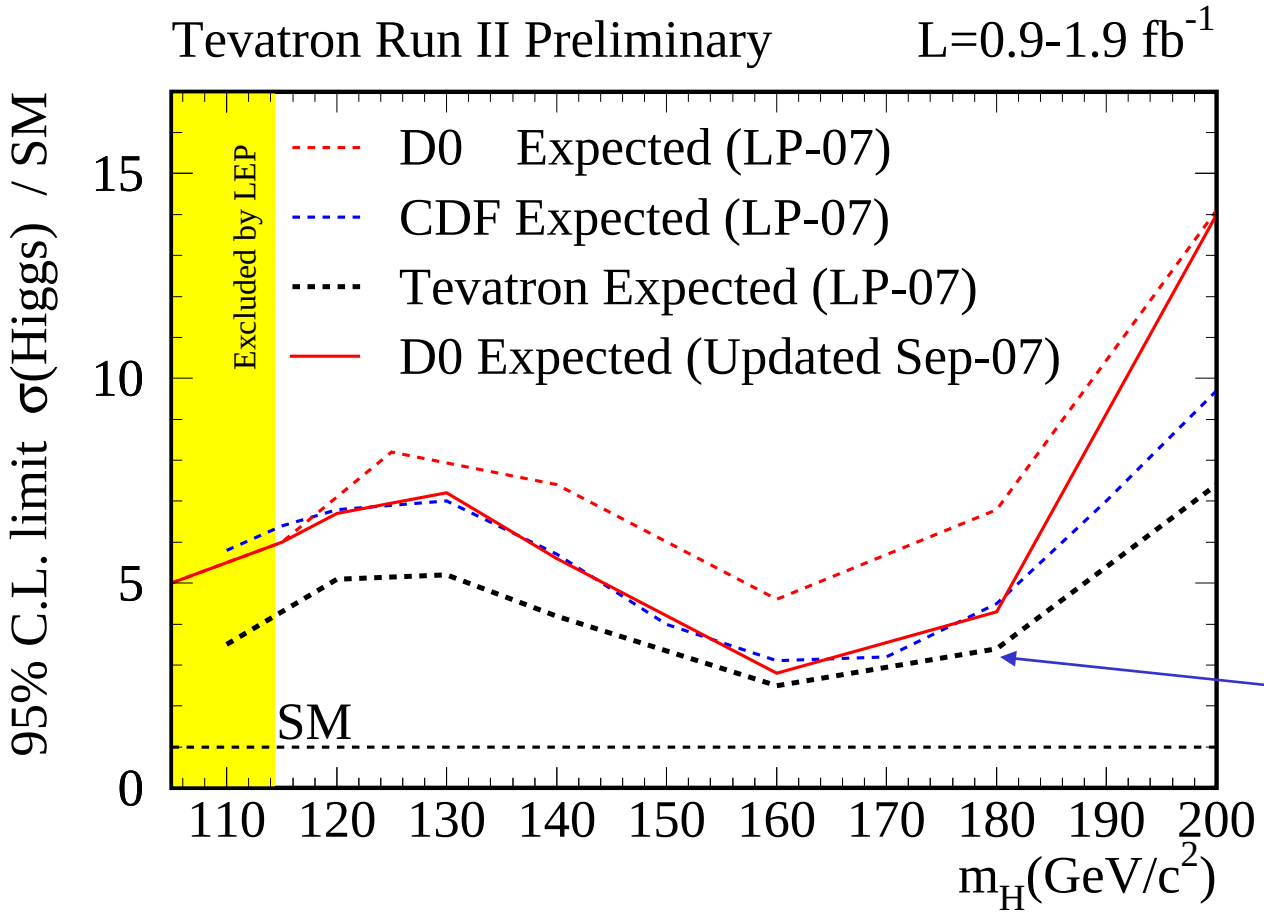
0.9-1.7 fb^{-1} analyzed

New results added since Lepton-Photon 07



Current Tevatron Limits

- For m_H=115, expected (observed) 95% CL relative to σ_{SM} = 4.3 (7.8)
- For m_H=160, expected (observed) 95% CL relative to σ_{SM} = 2.5 (1.4)



Combination does not yet include DØ September updates

Projecting Higgs Reach to 2010

- For background dominated searches, one generally expects the cross section limit to improve with integrated luminosity in proportion to sqrt(∫**Ldt)**
  - so far in Run II, limits have improved approximately in proportion to ∫**Ldt** itself
    - able to use more lepton acceptance
    - improvements in b-tagging
    - more/better multivariate techniques (neural nets)
    - better statistical treatment of separate channels with different signal/background
    - Increasing trigger efficiency
  - further improvements expected
    - Layer 0 enhancement in b-tagging
    - jet resolution optimization
    - Include additional channels: tau, WH→WWW→ℓℓℓ, H→WW→ℓνjj, etc.
    - even more/better multivariate techniques (matrix element)
    - Upgraded trigger efficiency
- With Tevatron running well, up to ~6 Higgs events/day are produced at DØ according to the Standard Model – we constantly improve our ability to find them

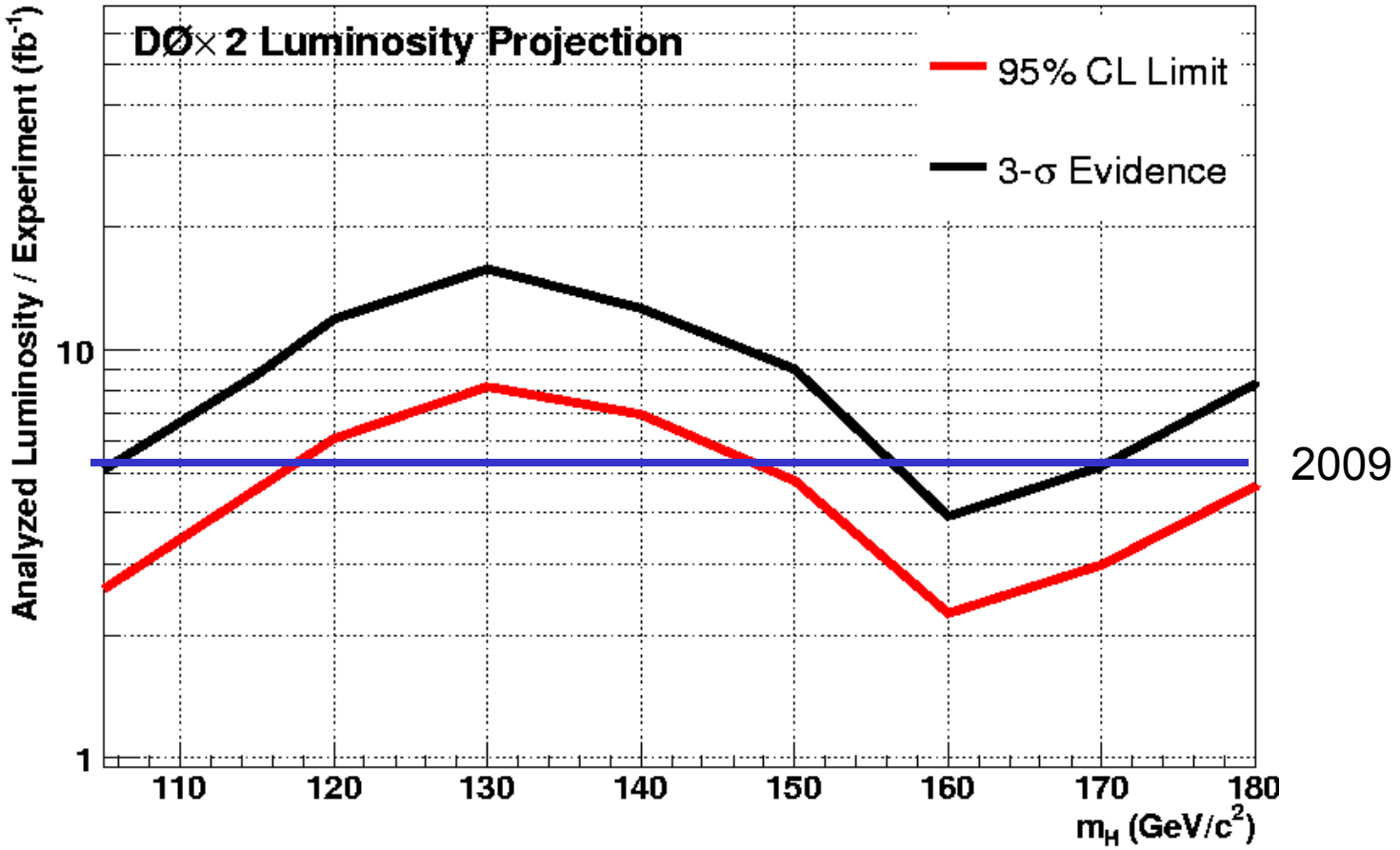
Projection assumptions: Low mass Higgs

- Well-predicted improvements (not yet implemented) – expected gains known with good precision
  - update ZH→vvbb with Neural Net
  - add single-b-tag channel to ZH→vvbb
  - include forward electrons in WH
  - include 3-jet sample in WH
  - b-tagging with Layer 0 (~8% per tag efficiency increase)
  - add semileptonic b-tags (~5% per tag efficiency increase)
  - scaling of systematic uncertainties as a function of luminosity
- Improvements in progress – gain factors estimated
  - dijet mass resolution (18% to 15% in σ(m)/m)
  - increased lepton efficiency (10% per lepton)
  - multivariate analyses (~20% in sensitivity)
- Additional improvements not yet included in projection
  - inclusion of tau channels
  - charm rejection in single b-tag analyses
  - optimizing H→WW at low mass
  - …

Projection assumptions: High mass Higgs

- Well-predicted improvements (not yet implemented) – expected gains known with good precision
  - scaling of systematic uncertainties as a function of luminosity
  - Run IIb H→WW optimized to match Run IIa performance
- Improvement in progress – gain factors estimated
  - increased lepton efficiency (10% per lepton)
  - multivariate analyses (~20% in sensitivity)
  - optimization of H→WW, HW→WWW at low mass
- Potential improvements not included in estimate
  - add τ channels
  - …

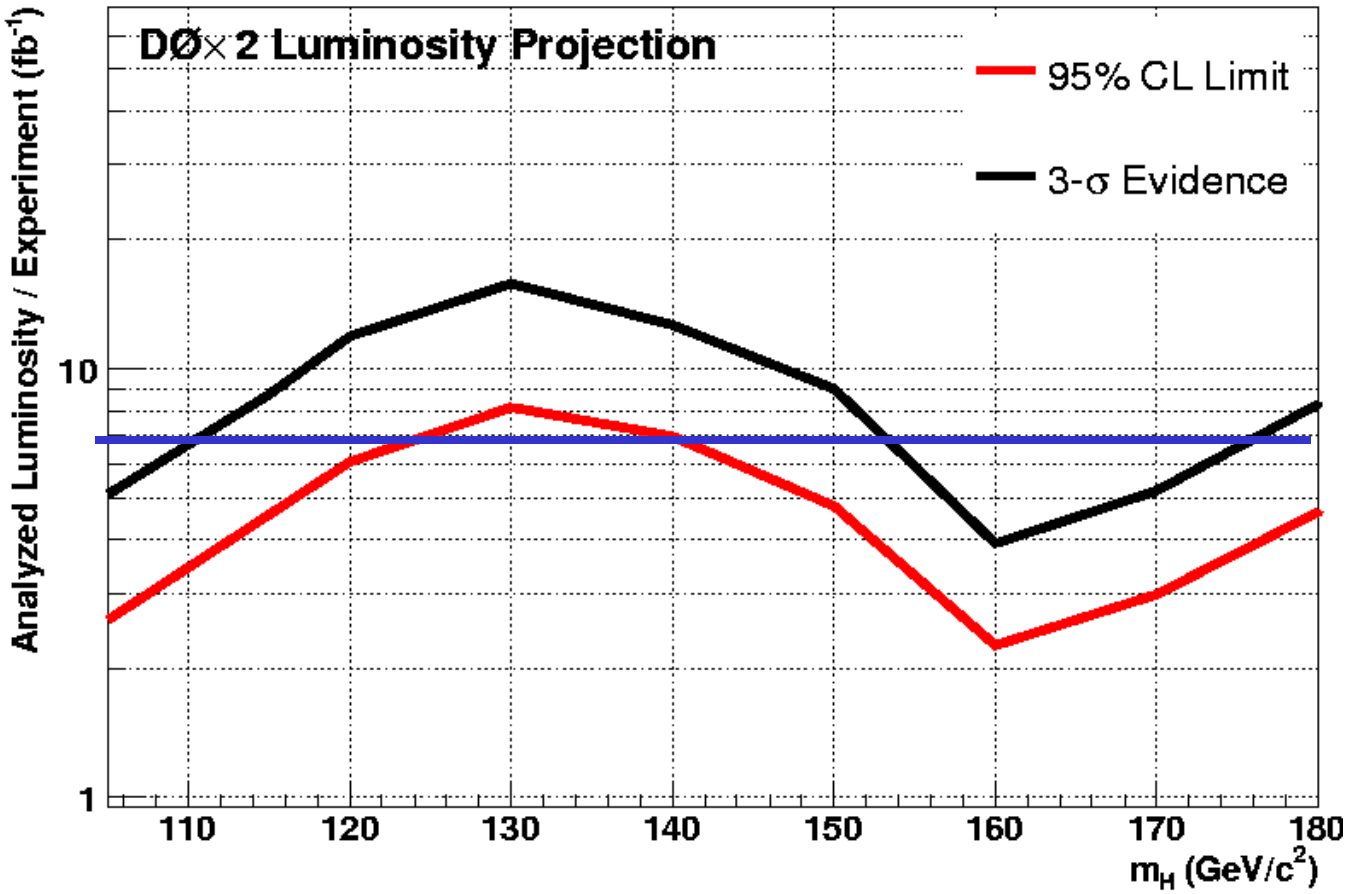
Median expected Higgs sensitivity



2009

Assumes two experiments

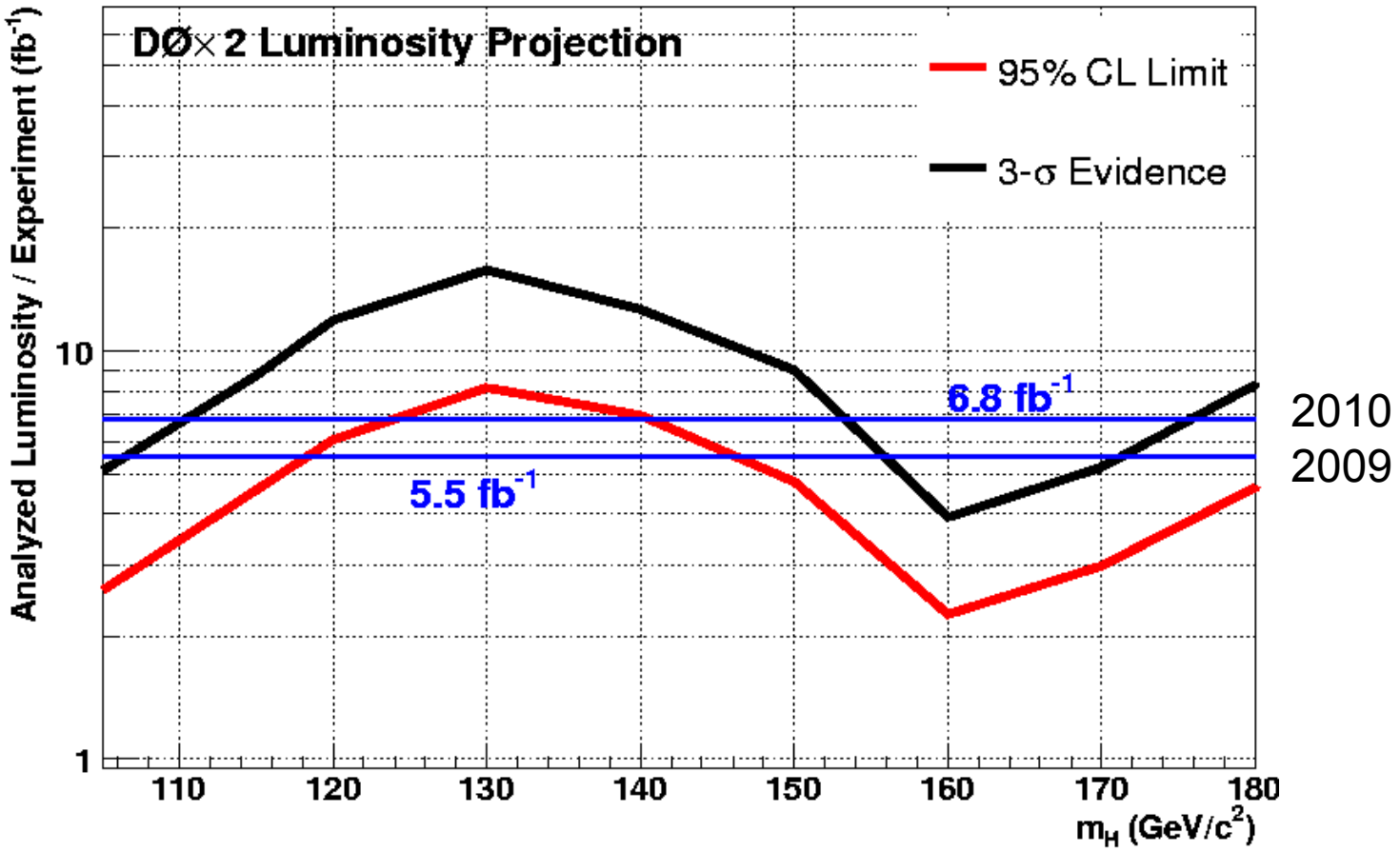
Median expected Higgs sensitivity



2010

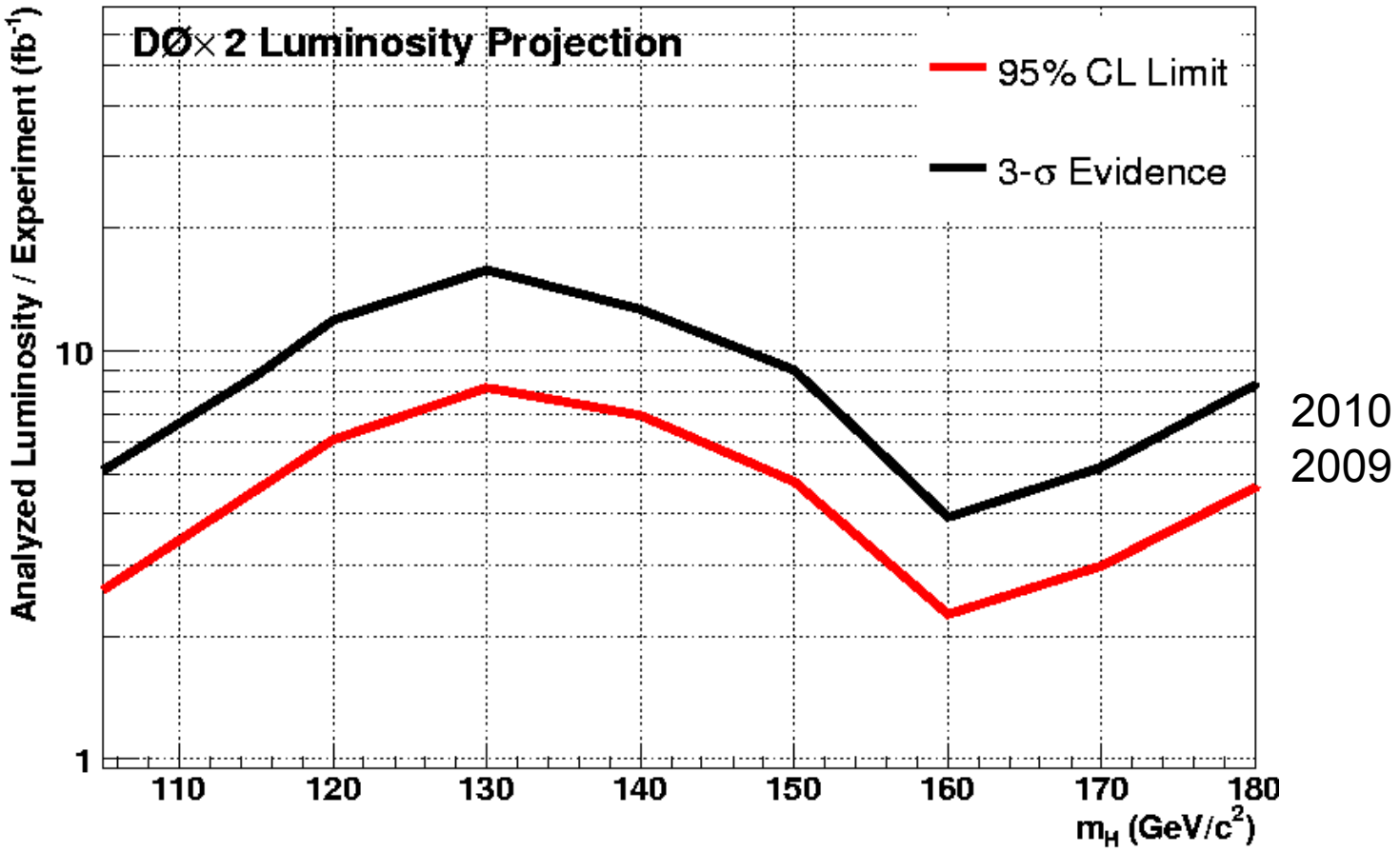
Assumes two experiments

Median expected Higgs sensitivity



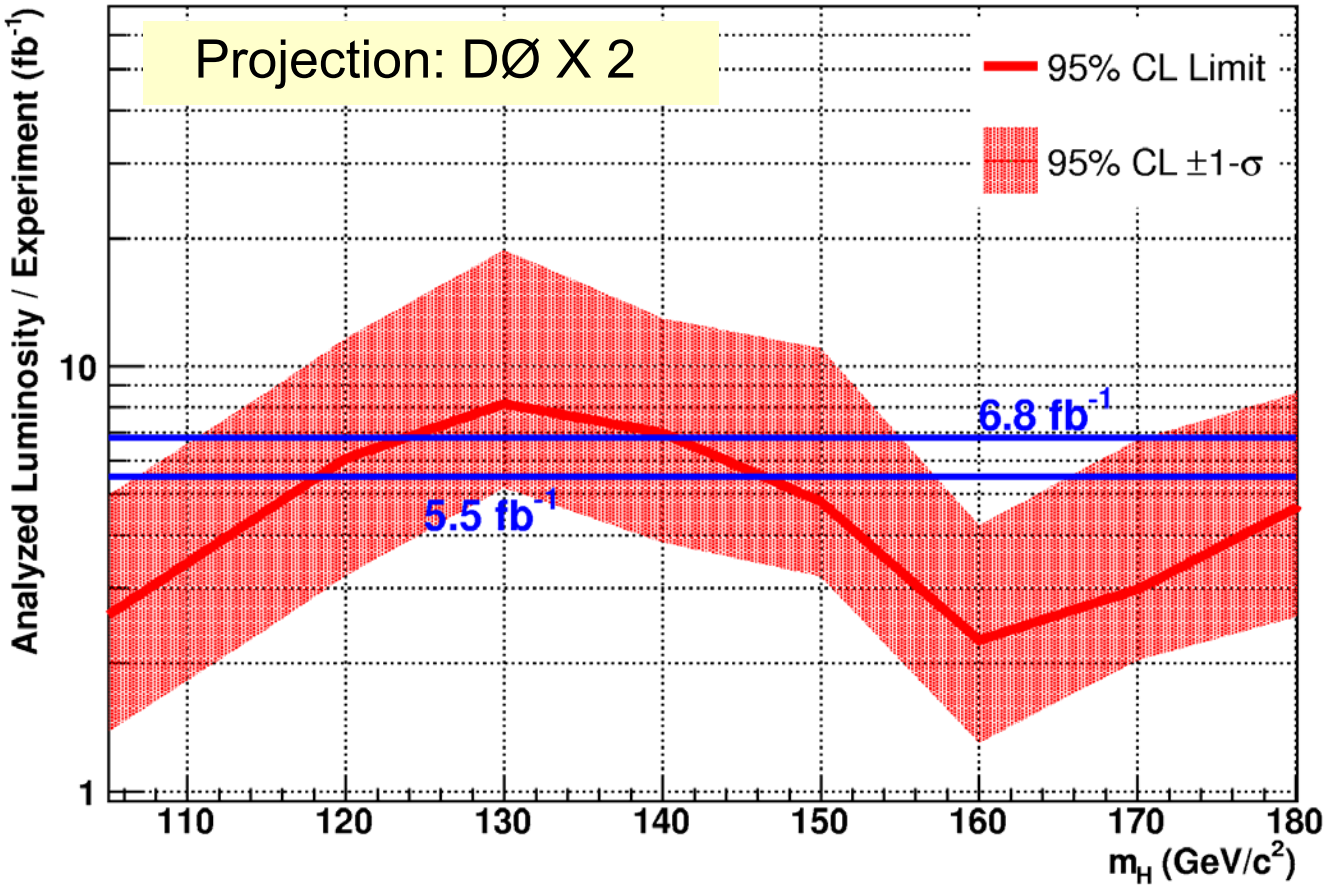
Assumes two experiments

Median expected Higgs sensitivity



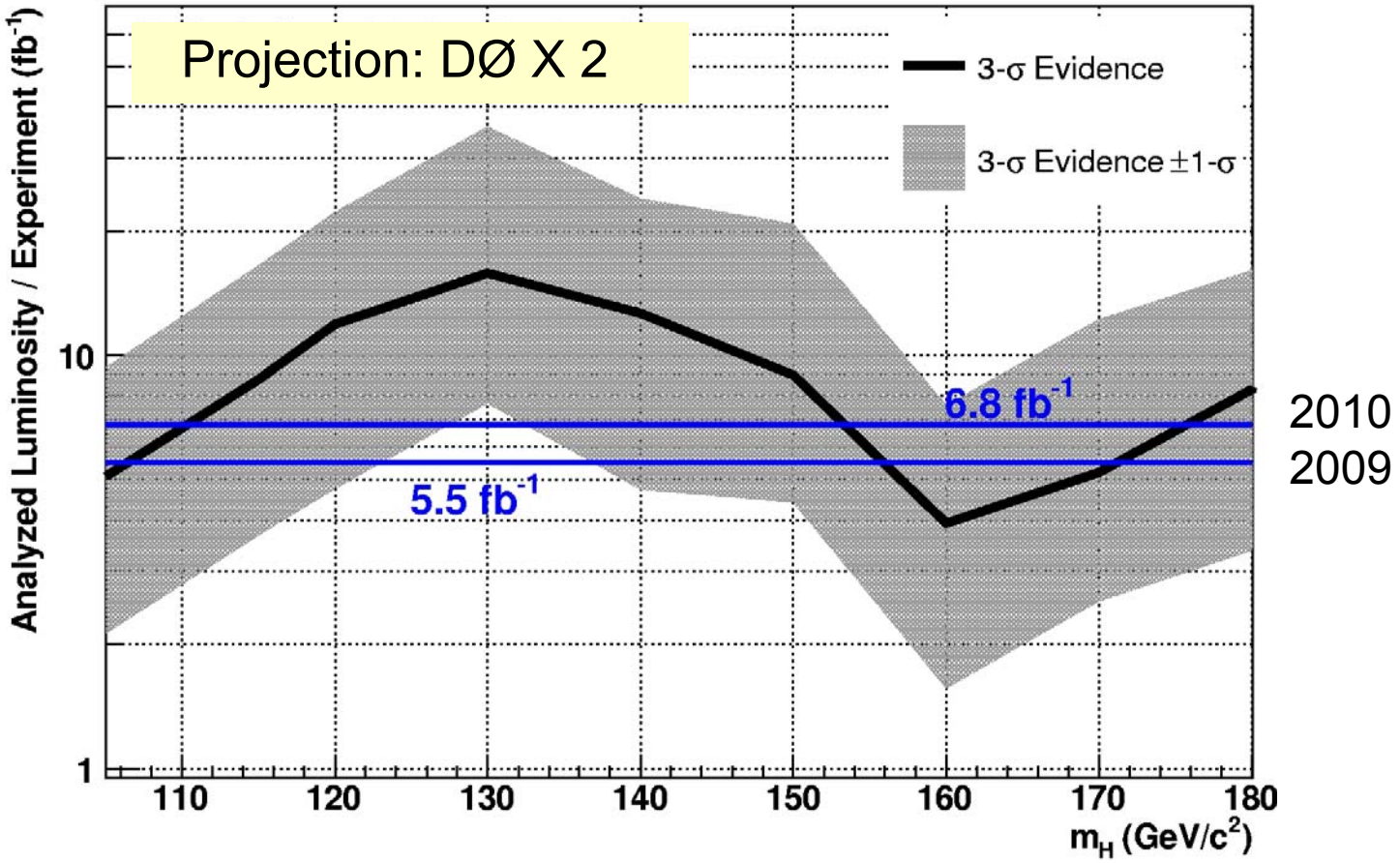
Assumes two experiments

Higgs sensitivity, 95% CL



Assumes two experiments

Higgs sensitivity, 3-σ evidence



Assumes two experiments

SM Higgs Prospects – executive summary

- With data accumulated by the end of 2010, we will be able to explore much of the SM Higgs mass region allowed by the constraints from precision measurements and LEP direct exclusion
  - Expected 95% CL exclusion over whole allowed range, (except possibly around 130 GeV) - assuming the Higgs does not exist at these masses
  - Three-sigma evidence for a Higgs possible over almost entire range, and probable for the low end and high end
- Work is underway to achieve and exceed these levels of sensitivity

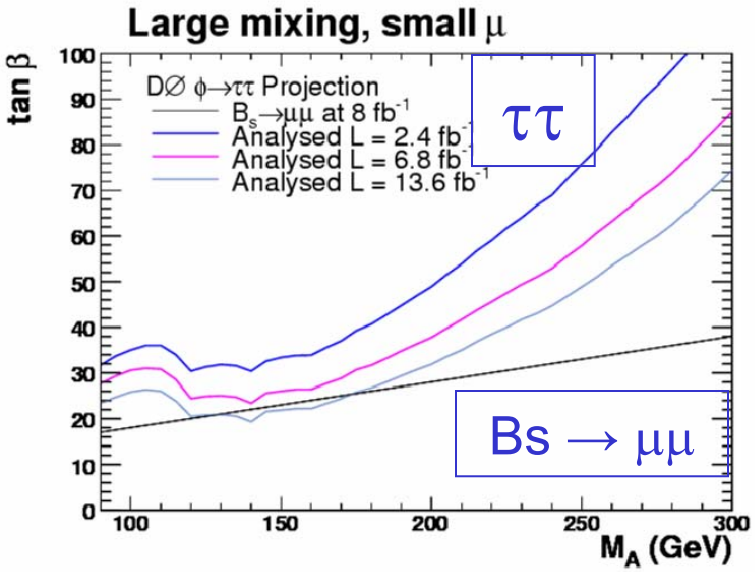
2010 Physics projection 2: MSSM SUSY Higgs

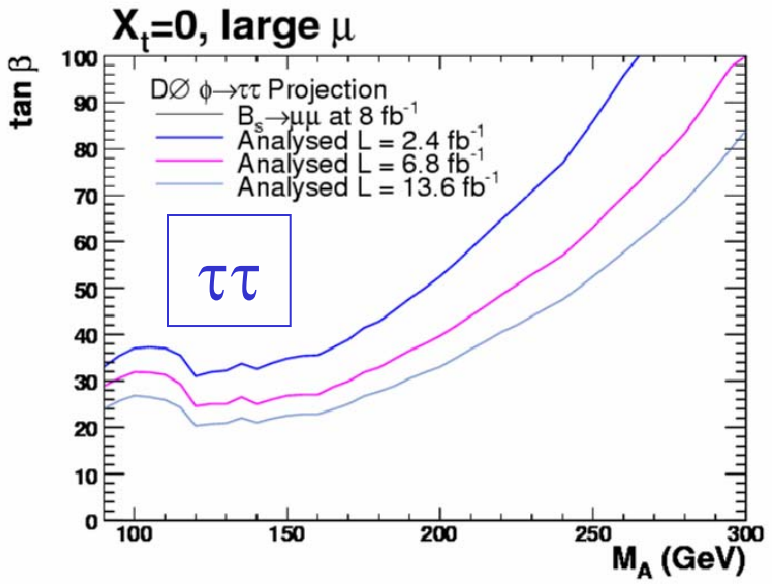
- SUSY-enhanced Higgs cross sections in proportion to $\tan^2\beta$
- We can have significant reach in ($\tan\beta$, M_A) plane. Interesting region $=m_t/m_b \sim 35$
- Complementary channels with similar sensitivity:
  - $h \rightarrow \tau\tau$
  - $hb(b) \rightarrow \tau\tau b(b)$, $bbb(b)$
- Could potentially benefit from optimized trigger strategy, so that new data will yield more sensitivity per fb^{-1} than old data
  - new tau triggering capabilities in new Run IIb calorimeter trigger
    - currently $h \rightarrow \tau_\mu \tau_{had}$ is triggered on single muon trigger with ~60-70% efficiency
  - also potential gains in bbb(b) trigger, which is currently ~60-70% efficient
- Synergies with SM Higgs search
  - b-tagging
  - Tau identification

MSSM Higgs limit projections

- Considered two sets of model parameters from Carena, Menon, & Wagner, arXiv:0704.1143v2
  - small μ, large stop mixing
  - large μ, no stop mixing
- Doubled luminosity approximates effect of two experiments

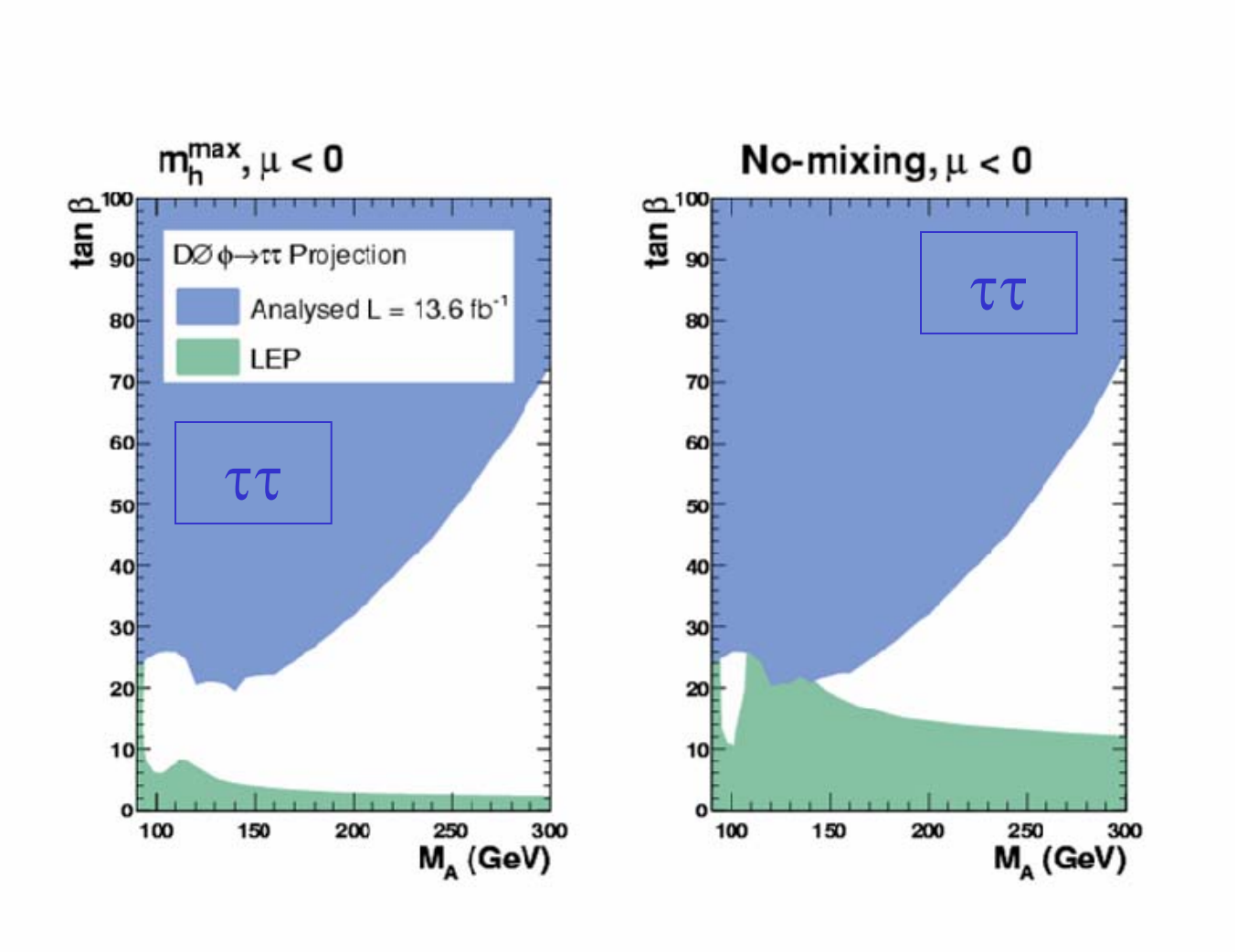
- Assumptions
  - 1% efficiency uncertainty per lepton
  - 5% QCD background uncertainty
  - 5% MC cross section uncertainty
  - 4% pdf uncertainty for signal
  - 20% improvement from multivariate techniques





MSSM Higgs – 95% CL expectations

Projections for full 2010 data set (2 experiments)

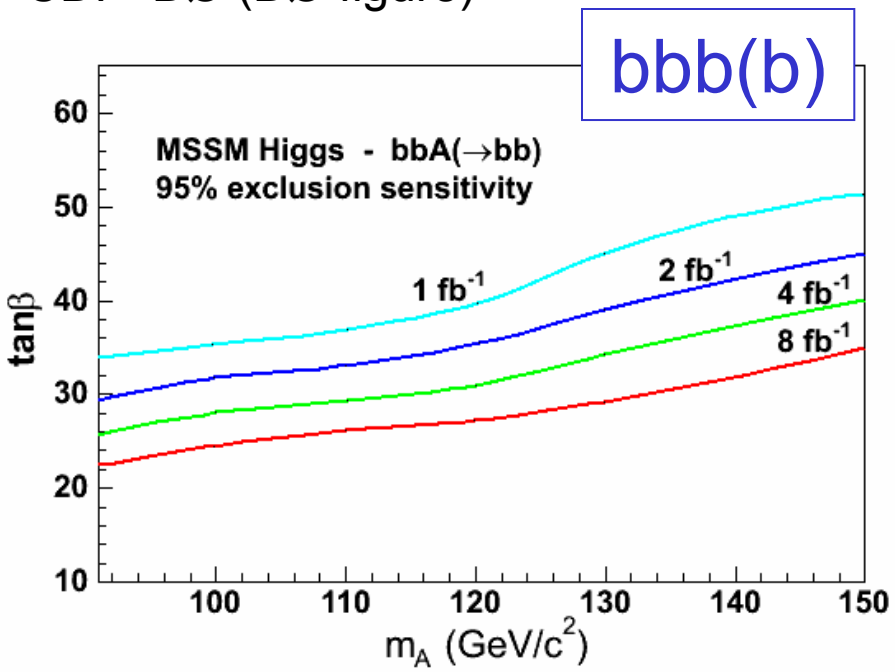


MSSM Higgs projections

Projections from 2005 study:

95% CL exclusions as a function of analyzed luminosity for CDF+D0

CDF+DØ (DØ figure)



hb(b)→ ττb(b)

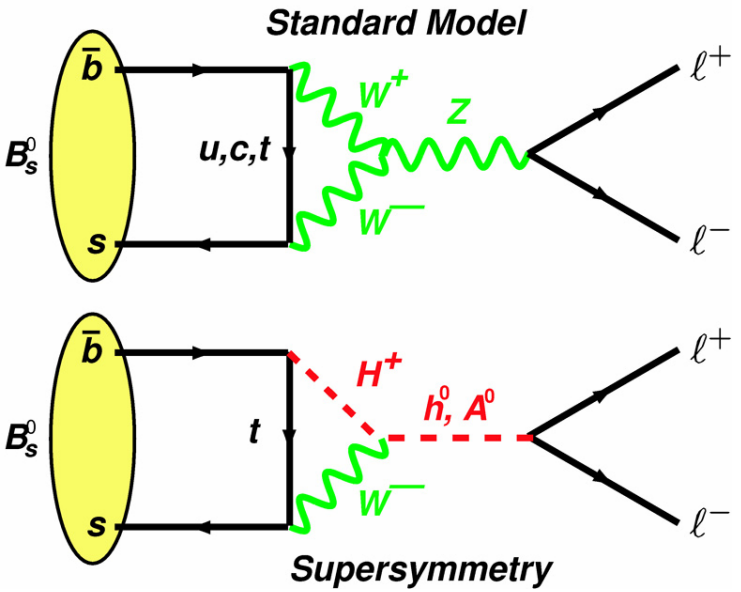
and

hb(b)→ bbb(b)

were not included in projections on previous slides, but are expected to each have comparable sensitivity

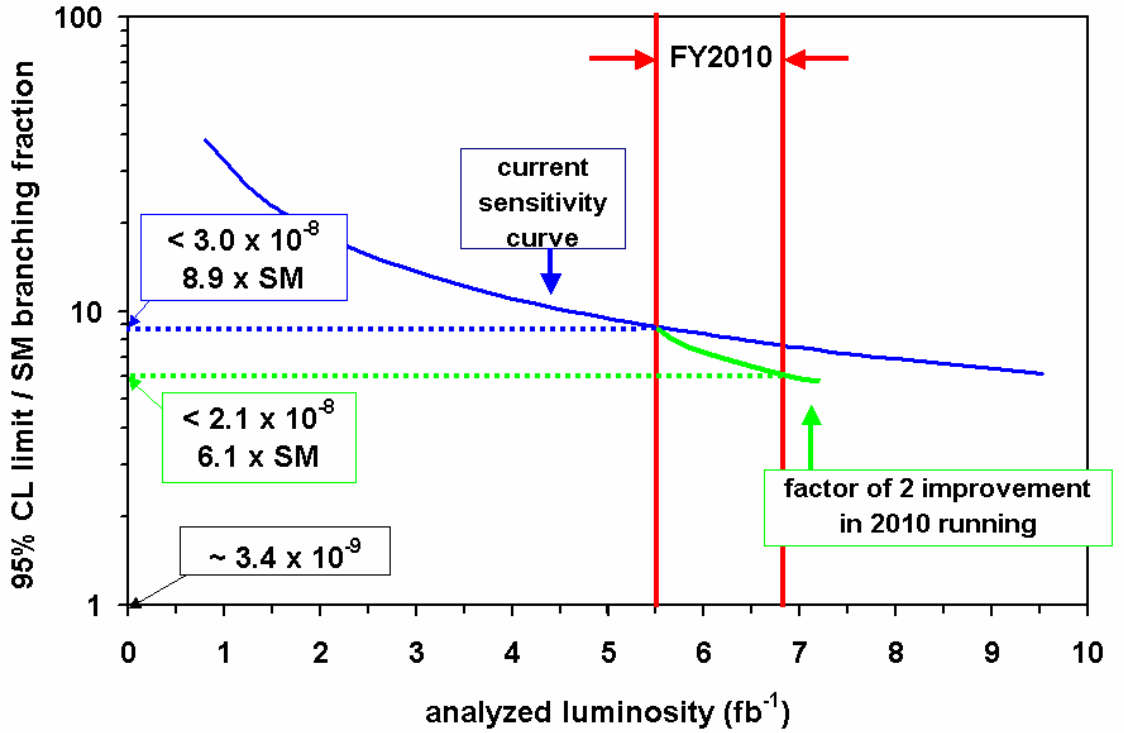
2010 projection 3: $B_s \rightarrow \mu\mu$

- Clean rare decay channel
  - SM: BR($B_s \rightarrow \mu\mu$)=(3.5±0.5)x10^{-9}
- BR can be enhanced significantly in new physics models
  - e.g. MSSM enhanced by $\tan^6\beta$
  - BR predictions as large as 10-10,000 times the SM prediction
- Trigger can be adjusted to give higher efficiency for low-mass muon pairs
  - Can have higher sensitivity in the new data



$B_s \rightarrow \mu\mu$ projections

- $B_s \rightarrow \mu\mu$ complements the SUSY higgs search with different channel in similar region of tanβ
- Assumptions for factor of two improvement in 2010
  - single muon triggering
  - looser dimuon trigger



Breadth

- These three cases (SM Higgs, SUSY Higgs, and $B_s \rightarrow \mu\mu$) make up part of a broader physics program
  - triggers for WH also give you single top and t-tbar
  - triggers for WW give you rare diboson final states (WW, WZ, ZZ)
  - …
- Many interesting measurement will still be statistics limited in 2009, and a 25% increase in statistics would give valuable improvements
  - single top, and measurement of $|V_{tb}|$
  - W helicity in top decays
  - top charge asymmetry
  - spin correlations in ttbar→dileptons
- New phenomena searches also benefit
  - chargino-neutralino trilepton
  - squark-gluino
  - …

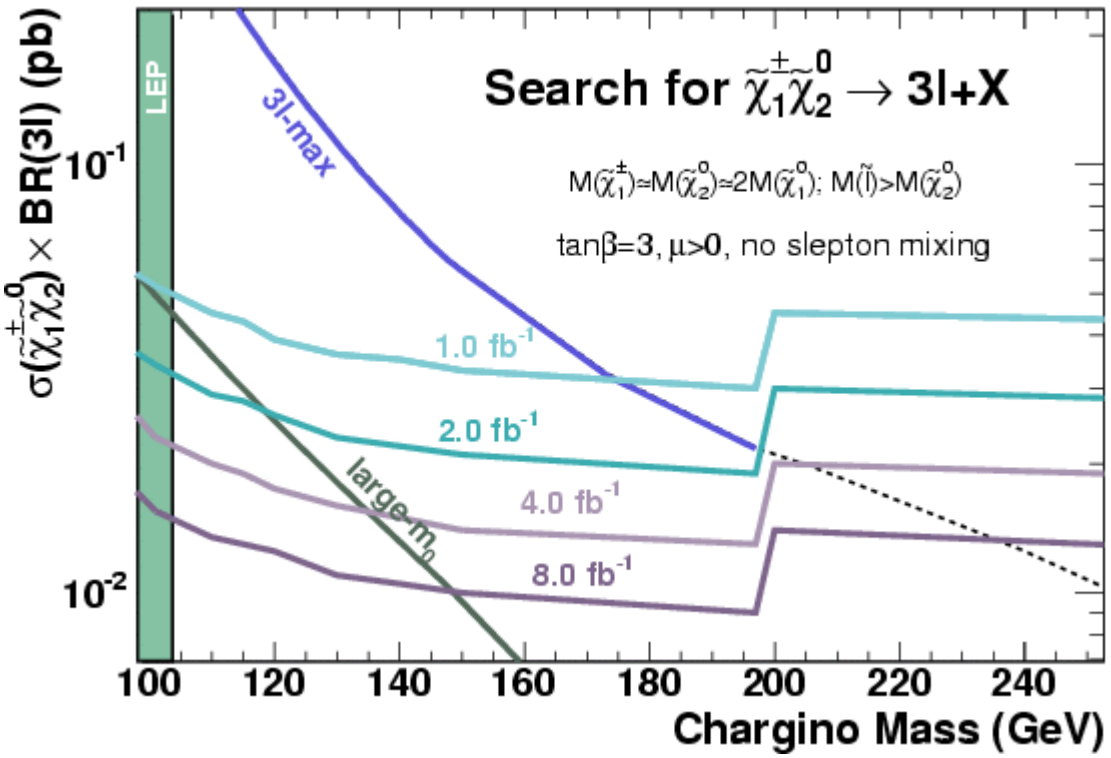
chargino+neutralino→tri-leptons

Study from 2005

- extrapolated from DØ results, but assuming two experiments

Some improvements assumed

- 50% reduction in background level
- fractional systematic uncertainty on background reduced to 10% level



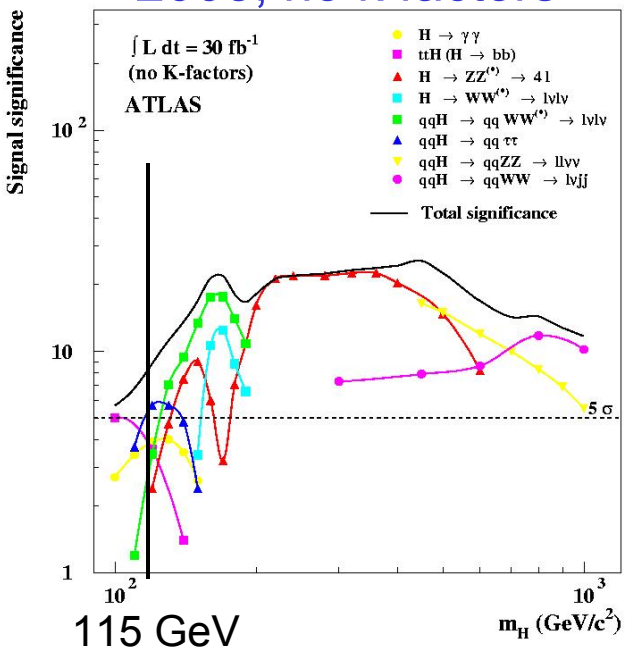
The Tevatron and the LHC

- At some point, the energy frontier will move from the Tevatron to the LHC
  - Some topics are still better explored at a pbar-p machine
    - top asymmetry
    - t-tbar spin correlations
    - searches for color-singlet resonances (q-qbar initial state)
    - …
  - Legacy measurements from the Tevatron will be worlds best for many years
    - top mass
    - W mass
    - …
  - The transition of the physics frontier is not instantaneous
    - Experience from DØ in early Run I and early Run 2: about 1-2 years required to publish first physics results

Complementing LHC

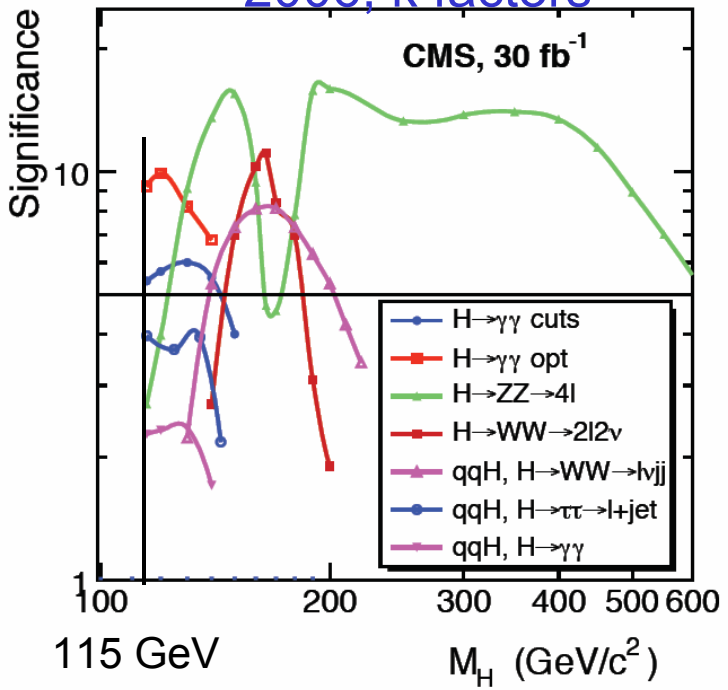
- Extending Tevatron Run II would help to ensure that there is no gap in physics between the end of the Tevatron program and the start of LHC physics results. There is strong synergy possible where Tevatron data could shed light on some LHC results
  - example: 115 GeV Higgs
    - lower masses are harder at LHC
    - production and decay modes used at the Tevatron are not used at LHC and are crucial to validate a SM Higgs.
  - indirect constraints from precision measurements at Tevatron

2003, no k factors



30 fb^{-1}

2006, k factors



Summary

- The DØ experiment is operating very well on all fronts
  - data taken with high operating efficiency
  - upgrades installed in 2006 working well
  - huge output of results to conferences and journals covering a wide scope of physics
  - already presenting results from data taken in May
    - evidence that reconstruction, analysis infrastructure, physics groups and review processes are all working well
- Physics prospect for additional data from a 2010 run
  - SM Higgs search is a strong motivation and is getting very exciting
    - expect to be sensitive to SM higgs for an extended range of unexplored masses
  - Good sensitivity for SUSY in MSSM Higgs and $B_s \rightarrow \mu\mu$
  - See a these benchmark topics as part of a broader physics program
- Other advantages by extending Run II for one additional year
  - Opportunity to react to new developments: hints, theory
  - Cross checks and calibrations
  - Synergy and continuity between Tevatron and LHC results

Conclusion

- DØ sees exciting physics prospects for a Tevatron run in 2010 which can enhance the legacy of the Tevatron in many ways
  - In particular, a modest increase in integrated luminosity can translate into a substantial increase range of Higgs mass exploration
- A positive recommendation from P5 soon would better allow us to line up people and resources
- Let's keep the 2010 opportunity open and move forward

Backups follow

Higgs Searches: What was new in Lepton Photon

- Improved techniques (WH, ZH)
  - NN in analysis and input to limit
  - Separate into n-tags and k-jets
  - Increased lepton acceptance (30%, e)
  - … and more …
- More luminosity:
  - WH, $WW_{(partial)}$ channels both with **IIa+IIb** data samples.
  - WH -> WWW* with IIa (1 fb^{-1})

SM Higgs constraints